THE

IAVAL ARCHITECT'S AND SHIPBUILDER'S

POCKET-BOOK

THE NAVAL ARCHITECT'S AND SHIPBUILDER'S POCKET-BOOK

OF

Formulæ, Rules, and Tables

AND

MARINE ENGINEER'S AND SURVEYOR'S HANDY BOOK OF REFERENCE

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Eleventh Edition

THOROUGHLY REVISED

WITH A SECTION ON AERONAUTICS

NEW YORK

THE NORMAN W. HENLEY PUBLISHING CO.

132 NASSAU STREET

1916

PRINTED BY

STEPHEN AUSTIN AND SONS, LTD.

HERTFORD.

PREFACE

TO

THE ELEVENTH EDITION.

THE need of a new edition of this Pocket-book has arisen through the continual development of the science of Naval Architecture, and the tendency towards standardization and regulation of parts of the structure and equipment of ships. Very many changes have been introduced, and much of the book has been rewritten, but where possible its form has been left unaltered. Its object remains the same as that stated in the Preface to the original edition, viz. to condense into a compact form all data and formulæ that are ordinarily required by the Shipbuilder or Naval Architect.

Amongst the new matter inserted, it is believed that the section on Speed and Horse-power will be useful in enabling ships of ordinary form to be approximately powered from the data therein given; a brief description of modern methods of powering and determining forms suitable from a propulsive standpoint has also been included. The necessity for economizing weight where possible without diminution of strength has led to the sections on Strength of Materials, Riveted Joints, and Stresses in Ships being considerably extended. Information concerning British Standard Sections, Screws, Keys, etc., has also been added, by permission of the Engineering Standards Committee. Finally, two new sections on Aeronautical matters will be of service, not only to those engaged in that modern and rapidly

developing branch of engineering, but also to Naval Architects on account of the kindred nature of the subjects, and of the direct application of many air data to questions relating to the resistance of bodies in water.

The remaining subjects treated, which were also included in previous editions, have now been brought completely up-to-date; the excision of obsolete data has enabled the new matter to be inserted without increase in the size of the book. The new tables of logarithms, etc., it is trusted, will be found of great practical convenience to those using them.

The scope and extent of the revision were arranged in the first place with the original author; although, owing to his death before the completion of the work, the absence of his advice and experience during the later stages has been felt and regretted, the reviser has had the benefit of securing great assistance from many sources during the preparation of the new edition. Among those who kindly contributed, the reviser is greatly indebted to Mr. A. W. Johns, the results of whose valued experience have been embodied in various parts of the book; the new sections 'Aerodynamics' and 'Aeronautics' are entirely due to him. Considerable aid in the treatment of Speed and Propellers has been rendered by Professor T. B. Abell, while Mr. E. F. Atkinson has supplied useful data concerning small craft and tugs. To these, and to many others to whom reference is made in the course of the book, the reviser tenders his cordial thanks. He also trusts that the numerous correspondents who have offered suggestions and pointed out errors in previous editions may be led to take the same kindly interest in the present revision.

L. W.

BARNES: *January* 1, 1916.

PREFACE

TO

THE FIRST EDITION.

THE OBJECT of this work is to supply the great want which has long been experienced by nearly all who are connected professionally with shipbuilding, of a Pocket-Book which should contain all the ordinary Formulæ, Rules, and Tables required when working out necessary calculations, which up to the present time, as far as the Author is aware, have never been collected and put into so convenient a form, but have remained scattered through a number of large works, entailing, even in referring to the most commonly used Formulæ, much waste of time and trouble. An effort has here been made to gather all this valuable material, and to condense it into as compact a form as possible, so that the Naval Architect or the Shipbuilder may always have ready to his hand reliable data from which he can solve the numerous problems which daily come before him. How far this object has been attained may best be judged by those who have felt the need of such a work.

Several elementary subjects have been treated more fully than may seem consistent with the character of the book. This, however, has been done for the benefit of those who have received a practical rather than a theoretical training, and to whom such a book as this would be but of small service were they not first enabled to

gather a few elementary principles, by which means they may learn to use and understand these Formulæ.

In justice to those authors whose works have been consulted, it must be added that most of the Rules and Formulæ here given are not original, although perhaps appearing in a new shape with a view to making them simpler.

There are many into whose hands this work will fall who are well able to criticise it, both as to the usefulness and the accuracy of the matter it contains. From such critics the Author invites any corrections or fresh material which may be useful for future editions.

SUMMARY OF CONTENTS.

	PAGES.
Signs and Symbols	1–3
Logarithms	4–7
Trigonometry	7–13
Curves (Conic Sections, Catenary, Cycloid, etc.)	13–18
Differential and Integral Calculus	19–21
Practical Geometry	22–36
Mensuration of Areas and Perimeters	36–49
Mensuration of Solids	49–59
Centres and Moments of Figures	59–69
Moments of Inertia and Radii of Gyration	69–75
Mechanical Principles	76–79
Centre of Gravity	80
Motion	81–83
Dynamics	84–88
Hydrostatics	88–89
Displacement, etc.	90–102
Weight and Centre of Gravity of Ships	102–109
Stability	110–143
Waves	143–149
Rolling	150–160
Speed and Horse-power	160–190
Propellers	190–197
Speed Trials and Tables	197–207
Sailing, Force of Wind	208–211

	PAGES.
Distances down Rivers	212–221
Weights and Dimensions of Materials	222–237
Wire and Plate Gauges	238–240
British Standard Sections	241–254
Notes on Materials	255–259
Weight and Strength of Materials	260–263
Admiralty Tests, etc., for Materials	263–284
Lloyds' Tests for Materials	284–285
Riveted Joints and Rivets	285–294
Braced Structures	294–300
Shearing Forces and Bending Moments of Beams	300–308
Strength of Materials and Stresses, etc.:	
General	309–312
Bending	312–327
Compression	328–331
Shear	332–337
Miscellaneous	337–339, 344
Keys and Wheel Gearing	340–344
Longitudinal Stresses in Ships	345–352
Mechanical Powers	353–363
Notes on Steering, Rudders, etc.	364–371
Launching	372–378
Armour and Ordnance	378–388
Notes on Machinery	388–390
Notes on Design	391–394
Fans and Ventilation of Ships	395–401
Hydraulics	402–404
Heat	405–406
Aerodynamics (Forces on Plates, etc.)	406–431

Aeronautics (Notes on Airships, etc.) . .	431–448
B. of T. Regulations for Marine Boilers, etc.	448–466
" " for Motor Passenger Vessels	466–469
" " for Ships	469–483
Strength of Bulkheads	483–487
International Regulations for Preventing Collisions at Sea	487–490
Tonnage	490–495
B. of T. Rules, etc., for Life-saving Appliances	495–502
" " for Emigrant Ships . .	502–505
Lloyds' Rules for determining Size of Shafts	506
" " for Ships	507–519
" " for Yachts of the International Rating Classes . . .	520–526
Anchors and Cables	527–533
British Standard Pipes and Screws . .	533–537
Ship Fittings	538–556
Seasoning and Measuring Timber . .	557–561
Miscellaneous Data	562–566
Dimensions and Weights of Blocks . .	567–571
Weight and Strength of Hemp and Steel-wire Rope	572–583
Lloyds' Rules for Yards, Masts, Rigging, etc.	584–593
Distances of Foreign Ports from London .	594
Paints, Caulking Varnishes, Galvanizing, etc.	595–605
English and Foreign Weights and Measures	606–627
Decimal Equivalents	628–631
Foreign Money	632–633
Discount and Equivalent Price Tables . .	634–635
Useful Numbers and Ready Reckoners .	636–638

Tables of Circular Measure . . .	639–641
Tables of Areas of and Circumferences of Circles	642–651
Tables of Areas of Segments of Circles .	652–654
Tables of Squares and Cubes and Roots of Numbers	655–699
Tables of Logarithms and Antilogarithms .	700–707
Tables of Exponential and Hyperbolic Functions	708–710
Tables of Hyperbolic Logarithms . .	711–715
Tables of Natural Sines, Tangents, etc. .	716–719
Tables of Logarithmic Sines, Tangents, etc. .	720–723
INDEX	725–742

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SIGNS AND SYMBOLS.

THE following are some of the signs and symbols commonly used in algebraical expressions:—

$=$ This is the sign of equality. It denotes that the quantities so connected are equal to one another; thus, 3 feet $=$ 1 yard.

$+$ This is the sign of addition, and signifies plus or more; thus, $4+3=7$.

$-$ This is the sign of subtraction, and signifies minus or less; thus, $4-3=1$.

$\times$ This is the sign of multiplication, and signifies multiplied by or into; thus, $4\times 3=12$.

$\div$ or / This is the sign of division, and signifies divided by; thus, $4\div 2=2$ or $4/2=2$.

( ) { } [ ] These signs are called brackets, and denote that the quantities between them are to be treated as one quantity; thus, $5\{3(4+2)-6(3-2)\}=5(18-6)=60$.

—— This sign is called the bar or vinculum, and is sometimes used instead of the brackets; thus, $\overline{3(4+2)-6(3-2)}\times 5=60$.

Letters are often used to shorten or simplify a formula. Thus, supposing we wish to express length $\times$ breadth $\times$ depth, we might put the initial letters only, thus, $l\times b\times d$, or, as is usual when algebraical symbols are employed, leave out the sign $\times$ between the factors and write the formula $l.b.d.$

When it is wished to express division in a simple form the divisor is written under the dividend; thus, $(x+y)\div z=\frac{x+y}{z}$

$:$, $::$, $\because$; These are signs of proportion; the sign $:$ = is to, the sign $::$ = as; thus, $1 : 3 :: 3 : 9$, 1 is to 3 as 3 is to 9.

$<$ This sign denotes less than; thus $2 < 4$ signifies 2 is less than 4.

$>$ This sign denotes more than; thus $4 > 2$ signifies 4 is more than 2.

$\because$ This sign signifies because.

$\therefore$ This sign signifies therefore. *Ex.*: $\because$ 9 is the square of 3 $\therefore$ 3 is the root of 9.

$\sim$ This sign denotes difference, and is placed between two quantities when it is not known which is the greater; thus $(x \sim y)$ signifies the difference between x and y.

$^{\circ}$, $'$, $''$ These signs are used to express certain angles in degrees, minutes, and seconds; thus 25 degrees 4 minutes 21 seconds would be expressed $25^{\circ}\ 4'\ 21''$.

Note.—The two latter signs are often used to express feet and inches; thus 2 feet 6 inches may be written $2'\ 6''$.

$\surd$ This sign is called the radical sign, and placed before a quantity indicates that some root of it is to be taken, and a small figure placed over the sign, called the exponent of the root, shows what root is to be extracted.

Thus $\sqrt[2]{a}$ or $\sqrt{a}$ means the square root of a.

$\sqrt[3]{a}$ „ cube „

$\sqrt[4]{a}$ „ fourth „

$\dfrac{\sqrt{a}}{b}$ This denotes that the square root of a has to be taken and divided by b.

$\dfrac{b}{\sqrt{a}}$ This denotes that b has to be divided by the square root of a.

$\sqrt{\dfrac{a+b}{a+d}}$ This denotes that the square root of $a+b$ has to be divided by the square root of $a+d$. It may also be written thus, $\sqrt{\dfrac{a+b}{a+d}}$, or $\dfrac{\sqrt{a+b}}{\sqrt{a+d}}$.

$\propto$ This is another sign of proportion. *Ex.*: $a \propto b$; that is, a varies as or is proportional to b.

∞ This sign expresses infinity; that is, it denotes a quantity greater than any finite quantity.

0 This sign denotes a quantity infinitely small, nought.

$\angle$ This sign denotes an angle. *Ex.*: $\angle abc$ would be written, the angle abc.

$\llcorner$ This sign denotes a right angle.

$\perp$ This sign denotes a perpendicular; as, $ab \perp cd$, i.e. ab is perpendicular to cd.

$\triangle$ This sign denotes a triangle; thus, $\triangle abc$, i.e. the triangle abc.

$\|$ This sign denotes parallel to. *Ex.*: $ab \| cd$ would be written, ab is parallel to cd.

f or F These express a function; as, $a = f(x)$; that is, a is a function of x or depends on x.

$\int$ This is the sign of integration; that is, it indicates that the expression before which it is placed is to be integrated. When the expression has to be integrated twice or three times the sign is repeated (thus, $\int\int$, $\int\int\int$); but if more than three times an index is placed above it (thus, $\int^n$).

D or d These are the signs of differentiation; an index placed above the sign (thus, d^i) indicates the result of the repetition of the process denoted by that sign.

Σ This sign (the Greek letter sigma) is used to denote that the algebraical sum of a quantity is to be taken. It is commonly used to indicate the sum of finite differences, just as the symbol $\int$ is used for indefinitely small differences.

g This sign is used to denote the acceleration due to gravity at any given latitude. Its value is about 32·2 in foot-second units and 981 in C.G.S. units.

π The Greek letter pi is invariably used to denote 3·14159; that is, the ratio borne by the diameter of a circle to its circumference.

e or ϵ This letter is generally used to denote 2·71828, which is the base of hyperbolic or Napierian logarithms.

$\lfloor\underline{n}$ or $n!$ termed 'factorial n', where n is a positive integer, denotes the product of the series $n\ (n-1)\ (n-2)\ .\ .\ .\ 2.1$. Thus, $\lfloor\underline{3} = 3.2.1$ or 6; and $\lfloor\underline{5} = 5.4.3.2.1 = 120$.

⨯ denotes the midship section or midship part of a vessel.

As the letters of the Greek alphabet are of constant recurrence in mathematical formulæ it has been deemed advisable to append the following table:—

Α α	Alpha.		Ι ι	Iota.		Ρ ρ	Rho.
Β β	Beta.		Κ κ	Kappa.		Σ σ s	Sigma.
Γ γ	Gamma.		Λ λ	Lambda.		Τ τ	Tau.
Δ δ	Delta.		Μ μ	Mu.		Υ υ	Upsilon.
Ε ϵ	Epsilon.		Ν ν	Nu.		Φ φ	Phi.
Ζ ζ	Zeta.		Ξ ξ	Xi.		Χ χ	Chi.
Η η	Eta.		Ο ο	Omicron.		Ψ ψ	Psi.
Θ θ	Theta.		Π π	Pi.		Ω ω	Omega.

LOGARITHMS.

Definition.—The logarithm of a number to a given base is the index of the power to which the base must be raised in order to become equal to the given number. Thus, if $a^x = N$, x is called the logarithm of N to base a.

The logarithms naturally occurring in analytical formulæ are to the base e, which is equal to $2{\cdot}718 \ldots$ or to the sum of the infinite series $1 + 1 + \frac{1}{\lfloor 2} + \frac{1}{\lfloor 3} + \frac{1}{\lfloor 4} + \ldots$; the values of the logarithms are obtained indirectly from the formula $\log_e(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \ldots$ Such logarithms are termed Napierian or hyperbolic logarithms; their values are given in the table on pp. 700–4.

When used to shorten arithmetical work, 'common logarithms' are employed, having 10 as their base.

Note.—The logarithm of 1 to any base is zero.

To Change the Base of a Logarithm.

Rule.—To obtain the logarithm of a number to base b from that to base a, multiply the latter logarithm by the logarithm of a to base b, or, equally, divide it by the logarithm of b to base a.

The logarithm of N to base a is denoted by $\log_a N$.

$$\therefore \log_b N = \log_a N \times \log_b a = \log_a N \div \log_a b.$$

Since $\log_e 10 = 2{\cdot}303 \ldots = \frac{1}{{\cdot}4343 \ldots}$, the hyperbolic logarithm of a number is obtained by multiplying its common logarithm by $2{\cdot}303$ or $\frac{1}{{\cdot}4343}$

Note.—The integral part of a logarithm is termed its *characteristic*, and the decimal part its *mantissa*.

To Find the Logarithm of a Number.

Rule.—The *characteristic* is one less than the number of digits in the integral part of the number; when there is no integral part, the characteristic is negative and is numerically one more than the number of cyphers between the decimal point and the first significant figure. In the latter case the minus sign is placed *over*, instead of before, the characteristic.

The *mantissa* is invariably positive; its value for numbers of three or less significant figures is directly obtained from the tables on pp. 700-4; for numbers having four significant

figures the tabular differences given in the columns on the right are employed thus—

Ex. 1.—Find log of 42·63.

$$\begin{array}{lrl} \text{log} & 42{\cdot}60 = & 1{\cdot}6294 \\ \text{tab. diff.} & 3 = & \underline{3} \\ \text{log} & 42{\cdot}63 = & 1{\cdot}6297 \end{array}$$

Ex. 2.—Find log of ·7897.

$$\begin{array}{lrl} \text{log} & {\cdot}7890 = & \bar{1}{\cdot}8971 \\ \text{tab. diff.} & 7 = & \underline{4} \\ \text{log} & {\cdot}7897 = & \bar{1}{\cdot}8975 \end{array}$$

Note.—The tabular difference is placed under the extreme right-hand figure or figures of the mantissa.

To find the Antilogarithm, or the Number corresponding to a given Logarithm.

Rule.—From the tables of antilogarithms, find the number corresponding to the given logarithm, using the tabular differences as before if four significant figures are required. If the characteristic is positive, the decimal point is so placed that the number of digits to the left is one more than the characteristic; if negative, the number of ciphers between the decimal point and the first significant figure is one less than the characteristic. For tables v. pp. 705-8.

Ex. 1.—Find the number whose logarithm is 5·8178.

$$\begin{array}{lrl} \text{antilog} & 8170 = & 6561 \\ \text{tab. diff.} & 8 = & \underline{14} \\ \text{antilog} & 8178 = & 6575 \end{array}$$

Number required is 657,500 to four significant figures.

Ex. 2.—Find the number whose logarithm is $\bar{3}$·1763

$$\begin{array}{lrl} \text{antilog} & 1760 = & 1500 \\ \text{tab. diff.} & 3 = & \underline{1} \\ \text{antilog} & 1763 = & 1501 \end{array}$$

Number required is ·001501.

To Multiply and Divide by Logarithms.

Rule.—Add together the logarithms of the numbers in the numerator, and those of the numbers in the denominator; subtract the latter sum from the former. The antilogarithm of the result is the number required.

Ex.: Evaluate $\frac{2}{3} \times \frac{17{\cdot}63}{35} \times \frac{2{\cdot}052}{{\cdot}008175}$

$$\begin{array}{lrl} \text{log } 2 & = & {\cdot}3010 \\ \text{log } 17{\cdot}63 & = & 1{\cdot}2462 \\ \text{log } 2{\cdot}052 & = & \underline{{\cdot}3122} \\ & & 1{\cdot}8594 \\ \text{subtract} & & \underline{\bar{1}{\cdot}9337} \\ \text{antilog} & & 1{\cdot}9257 \end{array} \qquad \begin{array}{lrl} \text{log } 3 & = & {\cdot}4771 \\ \text{log } 35 & = & 1{\cdot}5441 \\ \text{log } {\cdot}008175 & = & \underline{\bar{3}{\cdot}9125} \\ & & \bar{1}{\cdot}9337 \end{array}$$

= 84·28—the required result to four significant figures.

Note.—It is advisable to perform the operations of addition, multiplication, etc., on the mantissa and characteristic separately.

INVOLUTION AND EVOLUTION BY LOGARITHMS.

RULE.—Multiply the logarithm of the number by the index of the power to which it is to be raised. The antilogarithm of the result is the number required.

Ex. 1.—Find the cube and cube root of ·9873.

$$\begin{aligned} \log \cdot 9873 &= \bar{1}\cdot 9944 \\ \text{Multiply by } & \underline{\quad\quad 3} \\ & \bar{1}\cdot 9832 \end{aligned}$$

Antilog $\bar{1}\cdot 9832 = \cdot 9620$ which is the cube of ·9873.

$$\begin{aligned} \log \cdot 9873 &= \bar{1}\cdot 9944 \\ &= -3 + 2\cdot 9944 \\ \text{Divided by } 3) & \overline{\quad\quad\quad\quad} \\ & \bar{1}\cdot 9981 \end{aligned}$$

Antilog $\bar{1}\cdot 9981 = \cdot 9956$, which is the cube root of ·9873.

Ex. 2.—Evaluate $(20\cdot 4)^{1\cdot 83}$.

$$\log 20\cdot 4 = 1\cdot 3096, \text{ say } 1\cdot 310.$$

To multiply this by 1·83,

$$\begin{aligned} \log\ 1\cdot 310 &= \cdot 1173 \\ \log\ 1\cdot 83 &= \underline{\cdot 2625} \\ & \quad \cdot 3798 \end{aligned}$$

Antilog ·3798 = 2·397 ; antilog 2·397 = 242·5, the required result.

ACCURACY OF NUMERICAL CALCULATIONS.

In general, the accuracy of the result of a numerical calculation is the same as that of the factor liable to the greatest proportional error. Exceptional cases arise, viz., (*a*) when two nearly equal numbers are subtracted the percentage error in the result is usually greater than that in either of the numbers ; (*b*) when a large number of similar quantities, such as the ordinates in a displacement sheet, are added, the individual errors of measurement tend to neutralize, and the accuracy of the result is usually greater than that of its component factors ; (*c*) the percentage error in the n^{th} power of a number is n times that of a number ; thus in the cube the error is trebled, but in the cube root it is divided by three. Subject to these qualifications a considerable saving in the numerical labour of a calculation may be effected by limiting the number of significant figures at each stage to that appropriate to the accuracy of the result.

In calculations affecting the weight, buoyancy, stability, speed, strength, etc., of ships, a proportional error of at least 0·1 per cent, i.e. one in a thousand, may generally be expected ; three or, at most, four significant figures are sufficient in such cases, any additional figures being meaningless and redundant.

The slide rule, which mechanically performs the operations of multiplication, division, evolution, etc., by the aid (virtually) of three-place logarithms, is usually sufficiently accurate for the majority of such calculations; tables of logarithms, trigonometrical functions, etc., to four (or at most five) places of decimals are sufficient to perform any calculations in which rather greater accuracy is desired and can be obtained.

TRIGONOMETRY.

The *complement* of an angle is its defect from a right angle; thus if A denote the number of degrees contained in any angle, $90° - A$ is the number of degrees contained in the complement of that angle.

The *supplement* of an angle is its defect from two right angles; thus $180° - A$ is the number of degrees contained in the supplement of that angle.

TRIGONOMETRICAL RATIOS.

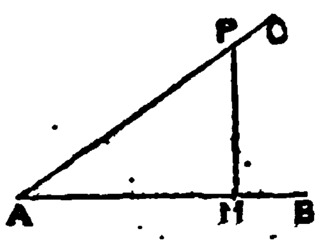


FIG. 1.

The trigonometrical ratios of an angle are defined as follows:—Let BAC (fig. 1) be any angle; take any point in either of the containing sides and from it draw a perpendicular to the other side; let P be the point in the side AC, and PM perpendicular to AB; let A denote the angle BAC. Then—

$$\text{sine } A = \frac{\text{perpendicular}}{\text{hypotenuse}} = \frac{PM}{AP}$$

$$\text{co-sine } A = \frac{\text{base}}{\text{hypotenuse}} = \frac{AM}{AP}$$

$$\text{tangent } A = \frac{\text{perpendicular}}{\text{base}} = \frac{PM}{AM}$$

$$\text{co-tangent } A = \frac{\text{base}}{\text{perpendicular}} = \frac{AM}{PM}$$

$$\text{secant } A = \frac{\text{hypotenuse}}{\text{base}} = \frac{AP}{AM}$$

$$\text{co-secant } A = \frac{\text{hypotenuse}}{\text{perpendicular}} = \frac{AP}{PM}$$

$$\text{versed sine } A = 1 - \cos A$$
$$\text{co-versed sine } A = 1 - \sin A.$$

These ratios depend only on the angle, and are independent of the position of the point P.

Measurement of Angles.

There are three modes of measuring angles, viz.—

1st. The sexagesimal or English method.
2nd. The centesimal or French method.
3rd. The circular measure.

The sexagesimal method and the circular measure only will be dealt with here.

The Sexagesimal Method.—In this method a right angle is supposed to be divided into 90 equal parts, each of which parts is termed a degree; each degree is divided into 60 equal parts called minutes, and each minute is divided into 60 equal parts called seconds. One degree 16 minutes 15 seconds or

$1^\circ\ 16'\ 15''$, is therefore equal to $1 + \frac{16}{60} + \frac{15}{3600}$ or 1·271 degrees.

The Circular Measure.—The unit of circular measure is an angle which is subtended at the centre of a circle by an arc equal to the radius of that circle. It is called a radian. Such an angle is equal to

$$\frac{2 \text{ right angles}}{\pi} = \frac{180^\circ}{3{\cdot}1416} = 57{\cdot}3^\circ \text{ nearly.}$$

The circular measure of an angle is equal to a fraction which has for its numerator the arc subtended by that angle at the centre of any circle, and for its denominator the radius of that circle.

Since the circumference of any circle is 2π times the radius, four right angles are equal to 2π radians. Consequently one right angle is equal to $\frac{\pi}{2}$ radians.

Approximate values of π are 3·1416 and $\frac{22}{7}$ and $\frac{355}{113}$

To find the circular measure of any angle expressed in degrees, minutes, and seconds.

Rule.—Multiply the measure of the angle in degrees by π, and divide by 180.

Ex.: Express $1^\circ\ 16'\ 15''$ or $1{\cdot}271^\circ$ in circular measure.

$$\frac{1{\cdot}271 \times \pi}{180} = {\cdot}0222 \text{ circ. meas.}$$

To find the measure of any angle in degrees, minutes, and seconds, the circular measure being given.

Rule.—Multiply the circular measure of the angle by 180, and divide by π.

Ex. 1.—Express in degrees, etc., an angle the circular measure of which is $\frac{2\pi}{3}$

$$\therefore \frac{2\pi \times 180}{3 \times \pi} = 120^\circ.$$

Tables giving the circular measure of angles are on pp. 639-41.

GENERAL FORMULÆ.

$$\sin^2 \theta + \cos^2 \theta = 1. \qquad \sec^2 \theta = 1 + \tan^2 \theta.$$

$$\operatorname{cosec}^2 \theta = 1 + \cot^2 \theta.$$

$$\sin (A + B) = \sin A \cos B + \cos A \sin B.$$

$$\cos (A + B) = \cos A \cos B - \sin A \sin B.$$

$$\sin (A - B) = \sin A \cos B - \cos A \sin B.$$

$$\cos (A - B) = \cos A \cos B + \sin A \sin B.$$

$$\sin A + \sin B = 2 \sin \frac{A+B}{2} \cos \frac{A-B}{2}$$

$$\cos A + \cos B = 2 \cos \frac{A+B}{2} \cos \frac{A-B}{2}$$

$$\sin A - \sin B = 2 \cos \frac{A+B}{2} \sin \frac{A-B}{2}$$

$$\cos B - \cos A = 2 \sin \frac{A+B}{2} \sin \frac{A-B}{2}$$

$$\tan (A + B) = \frac{\tan A + \tan B}{1 - \tan A \tan B}$$

$$\tan (A - B) = \frac{\tan A - \tan B}{1 + \tan A \tan B}$$

$$\sin 2A = 2 \sin A \cos A. \qquad \sin 3A = 3 \sin A - 4 \sin^3 A.$$

$$\cos 2A = \cos^2 A - \sin^2 A. \qquad \cos 3A = 4 \cos^3 A - 3 \cos A.$$

$$\sin \frac{A}{2} = \pm \sqrt{\frac{1 - \cos A}{2}} \qquad \cos \frac{A}{2} = \pm \sqrt{\frac{1 + \cos A}{2}}$$

If $t = \tan \frac{A}{2}$, $\sin A = \frac{2t}{1+t^2}$; $\cos A = \frac{1-t^2}{1+t^2}$; $\tan A = \frac{2t}{1-t^2}$

And when A, B, C are the three angles of a triangle,

$A + B + C = \pi$ radians or two right angles ;

and $\sin (A + B) = \sin (\pi - C) = \sin C.$

When A is any angle,

$$\sin (-A) = -\sin A. \qquad \cos (-A) = \cos A. \qquad \tan (-A) = -\tan A.$$

$$\sin (90^\circ - A) = \cos A. \qquad \cos (90^\circ - A) = \sin A. \qquad \tan (90^\circ - A) = \cot A.$$

$$\sin (90^\circ + A) = \cos A. \qquad \cos (90^\circ + A) = -\sin A. \qquad \tan (90^\circ + A) = -\cot A.$$

$$\sin (180^\circ - A) = \sin A. \qquad \cos (180^\circ - A) = -\cos A. \qquad \tan (180^\circ - A) = -\tan A.$$

$$\sin (180^\circ + A) = -\sin A. \qquad \cos (180^\circ + A) = -\cos A. \qquad \tan (180^\circ + A) = \tan A.$$

The algebraic formulæ for the sine and cosine are—

$$\sin A = \frac{e^{A\sqrt{-1}} - e^{-A\sqrt{-1}}}{2} = A - \frac{A^3}{3!} + \frac{A^5}{5!} - \dots$$

$$\cos A = \frac{e^{A\sqrt{-1}} + e^{-A\sqrt{-1}}}{2} = 1 - \frac{A^2}{2!} + \frac{A^4}{4!} - \dots$$

where A is in circular measure.

Where A is small, $\sin A = \tan A = A$; $\cos A = 1 - \frac{A^2}{2}$; $\sec A = 1 + \frac{A^2}{2}$

Tables of the trigonometrical functions are given on pp. 716–19.

Inverse Functions.

If $\sin a = x$, then $a = \sin^{-1}x$.
If $\cos a = y$, then $a = \cos^{-1}y$.
And so on.

Note.—$\sin^{-1}x$ is read 'inverse sine x', etc.

Logarithmic Functions.

The logarithms of the sines, cosines, etc., are denoted log sin, log cos, etc., and their values are given on pp. 720-3. For convenience the characteristic is in each case increased by the number 10.

Properties of Triangles.

Fig. 2.

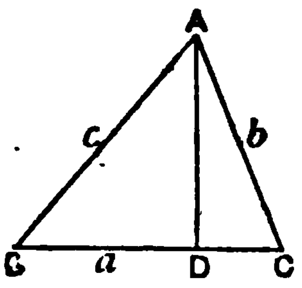


Fig. 3.

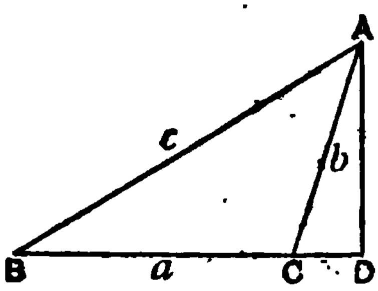
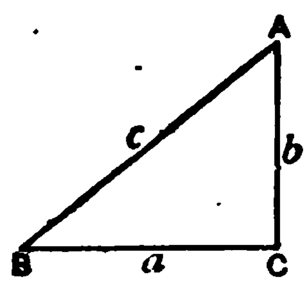


Fig. 4.



Note.—The sides opposite the angles A, B, C respectively will be denoted by the letters a, b, c. The angle BDA in figs. 2 and 3 is a right angle.

In fig. 2, where B and C are acute angles, we have—

$$\sin B = \frac{AD}{AB} = \frac{AD}{c}$$

$$\sin C = \frac{AD}{AC} = \frac{AD}{b}$$

$$\therefore \frac{\sin B}{\sin C} = \frac{AD}{c} \div \frac{AD}{b} = \frac{b}{c}$$

In fig. 3, where C is an obtuse angle, and in fig. 4, where C is a right angle, the proof is similar.

And therefore in any triangle $\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$.

Also $$\cos A = \frac{b^2 + c^2 - a^2}{2bc}.$$

$$\sin\frac{A}{2} = \sqrt{\frac{(s-b)(s-c)}{bc}}; \quad \cos\frac{A}{2} = \sqrt{\frac{s(s-a)}{bc}}.$$

$$\tan\frac{A}{2} = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}}; \quad \sin A = \frac{2}{bc}\sqrt{s(s-a)(s-b)(s-c)}$$

where $2s = a + b + c$.

$$a = b\cos C + c\cos B; \qquad \tan\frac{B-C}{2} = \frac{b-c}{b+c}\cot\frac{A}{2}.$$

Area of triangle $= \frac{bc}{2}\sin A = \sqrt{s\,(s-a)\,(s-b)\,(s-c)}$

SOLUTION OF TRIANGLES.

Every triangle has six elements—three sides and three angles. If any three of these be given (provided they be not the three angles) the triangle can be completely determined.

RIGHT-ANGLED TRIANGLES.

Let C be the right angle, and therefore c the hypotenuse.

(i.) Given hypotenuse (c) and one side (a).

$$b = \sqrt{c^2 - a^2}, \ \tan B = \frac{b}{a}, \text{ and } A = 90^\circ - B.$$

(ii.) Given the two sides (a and b).

$$c = \sqrt{a^2 + b^2}, \ \tan B = \frac{b}{a}, \text{ and } A = 90^\circ - B.$$

(iii.) Given an angle (B) and one of the sides (a).

$$b = a\tan B, \ c = a\sec B.$$

(iv.) Given an angle (B) and the hypotenuse (c).

$$a = c\cos B, \ b = c\sin B, \ A = 90^\circ - B.$$

ANY TRIANGLES.

(i.) Given the three sides, a, b, and c.

$$\tan\frac{A}{2} = \sqrt{\frac{(s-b)(s-c)}{s(s-a)}}, \ \tan\frac{B}{2} = \sqrt{\frac{(s-c)(s-a)}{s(s-b)}},$$

$$C = 180^\circ - A - B,$$

where $$2s = a + b + c.$$

(ii.) Given two sides, b and c, and the included angle A.

$$\tan\frac{B-C}{2}=\frac{b-c}{b+c}\cot\frac{A}{2}. \qquad \frac{B+C}{2}=90^\circ-\frac{A}{2}.$$

From $\frac{B-C}{2}$ and $\frac{B+C}{2}$ we can get B and C; and $a=b\frac{\sin A}{\sin B}$.

(iii.) Given two sides, b and c, and the angle B opposite to one of them.

$\sin C=\frac{c}{b}\sin B$. We thus obtain C; and $A=(180-B-C)$.

Also $$a=b\frac{\sin A}{\sin B}.$$

As there are generally two angles between 0° and 180° whose sine is $\frac{c}{b}\sin B$, two values of C are often admissible, and sometimes two triangles can be constructed.

(iv.) Given one side and two angles, a, B, and C.

$$A=180^\circ-B-C;\ b=a\frac{\sin B}{\sin A};\ c=a\frac{\sin C}{\sin A}.$$

(v.) When the three angles only are given, the absolute magnitude of the sides cannot be determined, but their ratios are given by $\frac{a}{\sin A}=\frac{b}{\sin B}=\frac{c}{\sin C}$.

TABLE GIVING THE SIGNS AND VALUES OF THE TRIGONOMETRICAL RATIOS FOR CERTAIN ANGLES.

Ratios	0°	Signs	30°	Signs	45°	Signs	60°	Signs	90°	Signs	120°
Sine	0	+	$\frac{1}{2}$	+	$\frac{1}{\sqrt{2}}$	+	$\frac{\sqrt{3}}{2}$	+	1	+	$\frac{\sqrt{3}}{2}$
Co-sine	1	+	$\frac{\sqrt{3}}{2}$	+	$\frac{1}{\sqrt{2}}$	+	$\frac{1}{2}$	+	0	−	$\frac{1}{2}$
Tangent	0	+	$\frac{1}{\sqrt{3}}$	+	1	+	$\sqrt{3}$	+	∞	−	$\sqrt{3}$
Co-tangent	∞	+	$\sqrt{3}$	+	1	+	$\frac{1}{\sqrt{3}}$	+	0	−	$\frac{1}{\sqrt{3}}$
Secant	1	+	$\frac{2}{\sqrt{3}}$	+	$\sqrt{2}$	+	2	+	∞	−	2
Co-secant	∞	+	2	+	$\sqrt{2}$	+	$\frac{2}{\sqrt{3}}$	+	1	+	$\frac{2}{\sqrt{3}}$

Ratios	Signs	135°	Signs	150°	Signs	180°	Signs	270°	Signs	360°
Sine	+	$\frac{1}{\sqrt{2}}$	+	$\frac{1}{2}$	+	0	−	1	−	0
Co-sine	−	$\frac{1}{\sqrt{2}}$	−	$\frac{\sqrt{3}}{2}$	−	1	−	0	+	1
Tangent	−	1	−	$\frac{1}{\sqrt{3}}$	+	0	+	∞	−	0
Co-tangent	−	1	−	$\sqrt{3}$	+	∞	+	0	−	∞
Secant	−	$\sqrt{2}$	−	$\frac{2}{\sqrt{3}}$	−	1	−	∞	+	1
Co-secant	+	$\sqrt{2}$	+	2	+	∞	−	1	−	∞

Hyperbolic Functions.

The hyperbolic functions are used in connection with the catenary; they are six in number, and are represented by affixing *h* to the symbols of the trigonometrical functions. They are determined by the following formulæ:—

$$\sinh x = \frac{e^x - e^{-x}}{2} = x + \frac{x^3}{\underline{|3}} + \frac{x^5}{\underline{|5}} + \ldots$$

$$\cosh x = \frac{e^x + e^{-x}}{2} = 1 + \frac{x^2}{\underline{|2}} + \frac{x^4}{\underline{|4}} + \ldots$$

$$\tanh x = \frac{\sinh x}{\cosh x} \qquad \coth x = \frac{\cosh x}{\sinh x} = \frac{1}{\tanh x}$$

$$\operatorname{sech} x = \frac{1}{\cosh x} \qquad \operatorname{cosech} x = \frac{1}{\sinh x}.$$

Note.—All formulæ connecting sin, cos, and tan can be converted into the corresponding formulæ for sinh, cosh, tanh by changing $\sin x$ to $\sqrt{-1}\sinh x$, $\cos x$ to $\cosh x$, and $\tan x$ to $\sqrt{-1}\tanh x$; thus $\cosh^2 x - \sinh^2 x = 1$; $\operatorname{sech}^2 x + \tanh^2 x = 1$; etc.

The values of $\sinh x$, $\cosh x$, e^x, and e^{-x} are given in the tables on pp. 708–10.

CURVES.

CONIC SECTIONS.

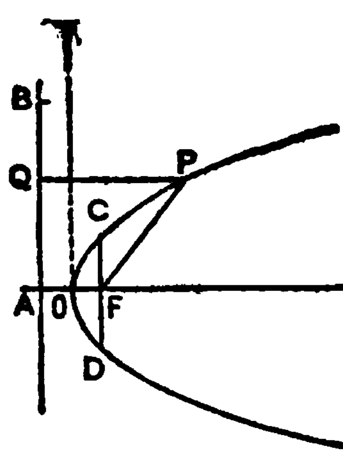
Definition.—The locus of a point which moves so that its distance from a fixed point is always in a constant ratio to its perpendicular distance from a fixed straight line is called a conic section.

The fixed point is called the focus, the constant ratio the eccentricity, and the fixed straight line the directrix.

The straight line passing through the focus and perpendicular to the directrix is called the axis.

Parabola.

Fig. 5.



The conic section is called a parabola when the eccentricity is equal to unity.

In fig. 5, F is the focus, AB the directrix, AX the axis, O the intersection of the curve with the axis, OY a line perpendicular to AX, and P any point on the curve; then PQ = PF.

The equation of the curve with OY and OX as axes is

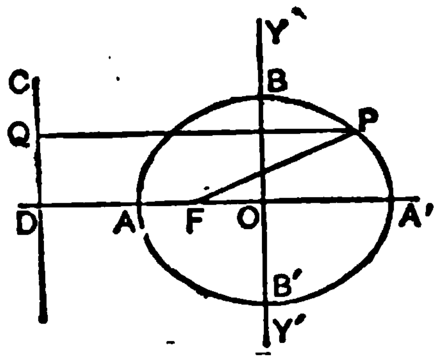
$$y^2 = 4\,ax, \text{ where AO} = \text{OF} = a.$$

A parabola may also be defined as the section of a cone cut by a plane parallel to one of the slant sides.

ELLIPSE.

The conic section is called an ellipse when the eccentricity is less than unity.

FIG. 6.



In fig. 6 CD is the directrix, F the focus, AA′ the major axis, O the middle point of AA′, and BB′ the minor axis, down through O, perpendicular to the axis, and P any point on the curve so that $\frac{PF}{PQ}$ = the eccentricity e. The equation to the curve with OA′, OY as axes is—

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1.$$

Also OA = OA′ = a; OB = OB′ = b; $a^2 - b^2 = a^2 e^2$; OF = ae; OD = $\frac{a}{e}$

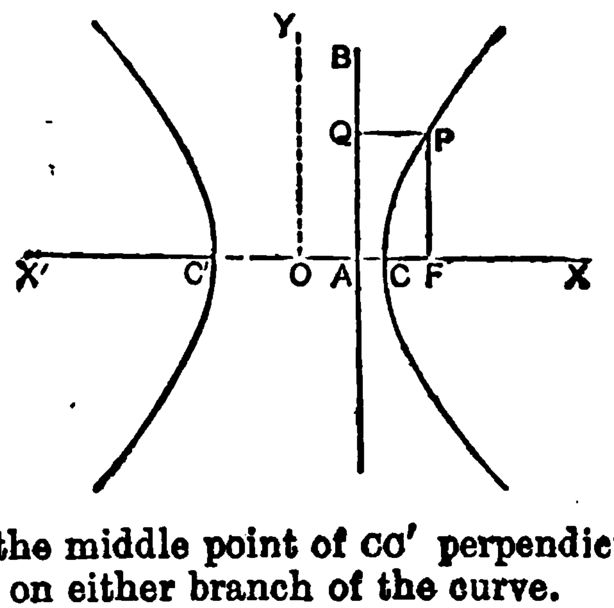
An ellipse may also be defined as the intersection of a cone by a plane passing through its slant sides, but not perpendicular to the axis.

HYPERBOLA.

The conic section is called a hyperbola when the eccentricity is greater than unity.

In fig. 7 AB is the directrix, F the focus, XX′ the axis, CC′ the points where the curve intersects the axis, OY a line

FIG. 7.



drawn through the middle point of CC′ perpendicular to the axis, and P any point on either branch of the curve.

Then $\frac{PF}{PQ}$ = the eccentricity e.

Taking OX and OY as axes the equation to the curve is—

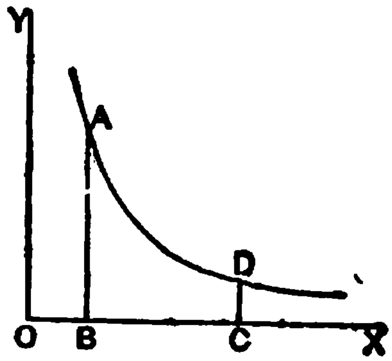
$$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1.$$

Also OC = OC′ = a; $a^2 + b^2 = a^2 e^2$; OF = ae; OA = $\frac{a}{e}$

If the sides of a cone be produced beyond the vertex so as to form a second cone with the same axis as the first, and these two cones be cut by a plane, the section will be a hyperbola.

If b be made equal to a in the above equation, it becomes $x^2 - y^2 = a^2$, which is a *rectangular* hyperbola. By turning

FIG. 8.



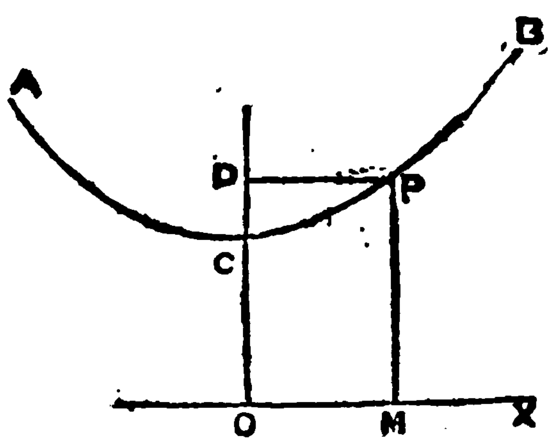
the axis through an angle of 45°, the equation becomes of the form $xy = c^2$ (fig. 8), where $c^2 = \frac{1}{2} a^2$

CATENARY.

(See pp. 27 and 28 for method of construction.)

If a uniform chain be freely suspended from two points, A and B, the curve in which it will hang is termed a common catenary ; the parameter OC is equal to the length of a piece of the chain whose weight is equal to the tension at the lowest point O in the curve.

FIG. 9.



The directrix OX is a horizontal line drawn through the extremity O of the parameter.

The tension at any point P in the curve is equal to the weight of a piece of the chain whose length is equal to the ordinate PM.

Equations to the Catenary (see fig. 9).

Take OX (horizontal) and OD (vertical through O the lowest point) as axes.

x = abscissa OM. y = ordinate PM. c = parameter OO.
s = length CP of chain. w = weight of chain per linear unit run.
T = tension at P. ϕ = angle to horizontal of chain at P.
e = base of hyperbolic logarithms = 2·718 . . .

$$y = c \cosh\frac{x}{c} = \frac{c}{2}\left(e^{\frac{x}{c}} + e^{-\frac{x}{c}}\right) = \sqrt{(c^2 + s^2)}.$$

$$s = c \sinh\frac{x}{c} = \frac{c}{2}\left(e^{\frac{x}{c}} - e^{-\frac{x}{c}}\right) = \sqrt{(y^2 - c^2)}.$$

$$T = wc \cosh\frac{x}{c} = wy. \quad \text{Dip (DC in fig.)} = c\,(\cosh\frac{x}{c} - 1).$$

$$\tan\phi = \sinh\frac{x}{c} = \frac{s}{c} \qquad \sec\phi = \cosh\frac{x}{c} = \frac{y}{c}$$

The values of the hyperbolic functions (sinh x, cosh x, etc.) are tabulated on pp. 708-10. Examples showing their application to the catenary are given below.

Approximate Equations for flat piece of chain, nearly horizontal.

$$\delta = \text{dip DC} = y - c\,; \quad x = \tfrac{1}{2} \text{ span}.$$

$$\delta = \frac{1}{2}\,\frac{x^2}{c} + \frac{1}{24}\,\frac{x^4}{c^3} = \sqrt{\left(\frac{3}{2}\,x\,(s - x)\right)}$$

$$c = \frac{1}{2}\,\frac{x^2}{\delta} + \frac{1}{6}\,\delta = \frac{s^2 - \delta^2}{2\delta} = x\sqrt{\frac{x}{6(s-x)}}$$

$$s = x + \frac{1}{6}\,\frac{x^3}{c^2} = x + \frac{2}{3}\,\frac{\delta^2}{x}$$

Tension* = $\frac{1}{8}$ total weight × span ÷ sag at centre.

Note.—When the points of support are in the same horizontal plane, the catenary is symmetrical about a vertical line passing midway between them, and the preceding formulæ can be directly employed to determine the particulars of the curve.

Ex. 1.—A chain weighing 15 lb. per foot run is suspended between two points at the same level and 100 feet apart. The dip is observed to be 40 feet. Determine the length of chain, the maximum tension, and the inclination at the supports.

$$\text{Dip} = c\left(\cosh\frac{x}{c} - 1\right). \quad \text{Here dip} = 40\,; \; x = \frac{100}{2} = 50.$$

Hence $40 = c\left(\cosh\frac{50}{c} - 1\right)$. By trial, from the tables (p. 709), $c = 36$ approximately.

Length of chain $= 2s = 2c \sinh\frac{x}{c} = 135$ feet approximately.

* On substituting 'pressure' for 'weight', this is applicable to a rope or net under uniform pressure when sag is moderate.

Maximum tension occurs at supports and is given by—

$$T = wc \cosh \frac{x}{c} = 1150 \text{ lb.}$$

Angle at supports $= \phi = \sec^{-1} \cosh \frac{x}{c} = 62°$.

Ex. 2.—The chain in the preceding example is tightened until the length suspended is reduced to 120 feet. To determine the dip—

$s = c \sinh \frac{x}{c}$. Here $s = 60$; $x = 50$.

Hence $60 = c \sinh \frac{50}{c}$. By trial, from the tables, $c = 47$ approximately.

$$\text{Dip} = c\left(\cosh \frac{x}{c} - 1\right) = 29{\cdot}2 \text{ ft.}$$

Ex. 3.—If the chain in example 2 is tightened further until the dip is reduced to 9 feet, determine the length, and the tension.

Using the approximate formulæ for a flat chain—

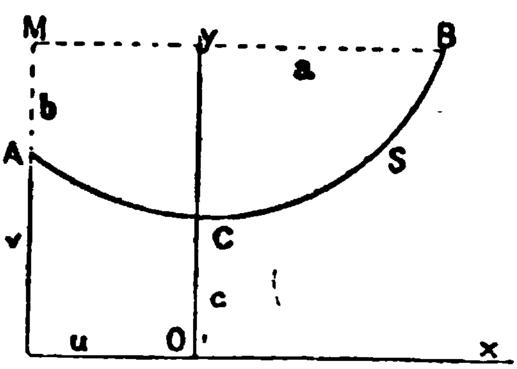
$$\text{Length} = 2s = 2x + \frac{4}{3}\frac{\delta^2}{x}$$

Here $x = 50$, $\delta = 9$. Hence length = 102 feet approximately.

$$\text{Tension} = wc = w\left(\frac{1}{2}\frac{x^2}{\delta} + \frac{\delta}{6}\right) = 2{,}105 \text{ lb.}$$

Formulæ for the Catenary between two points not in the same horizontal plane.

FIG. 10.



Take axes as before (fig. 10), let A, B be the points of support

S = total length of chain ACB.

b = vertical distance AM between A and B.

a = horizontal distance MB between A and B.

v = height of A above axis OX

$$\sqrt{S^2 - b^2} = 2c \sinh \frac{a}{2c} \qquad S = 2c \sinh \frac{a}{2c} \cosh \frac{a - 2u}{2c}$$

$$b = 2c \sinh \frac{a}{2c} \sinh \frac{a - 2u}{2c} \qquad v = c \cosh \frac{u}{c}$$

Ex. 1.—A chain of length 100 feet is suspended between supports distant 50 feet horizontally and 60 feet vertically. Determine the position of its lowest point, and the maximum tension (weight 10 lb. per foot run).

Here $S = 100$; $a = 50$; $b = 60$.

By trial from the above formulæ, using the tables.

$$c = 14{\cdot}2;\ u = 15{\cdot}2;\ v = 23.$$

$$\text{Maximum tension (at B)} = w\,c \sinh \frac{a-u}{c} = 820 \text{ lb.}$$

Note.—If a is negative, the lowest point of the catenary occurs outside the point of support A; in that case no part of the chain is horizontal.

Cycloidal Curves.

Definition.—If a circle be made to roll without slipping on a straight line, the locus of a point P (fig. 11) on its circumference is the cycloid MNM′, and that of any point Q inside the circle is the trochoid RSR′.

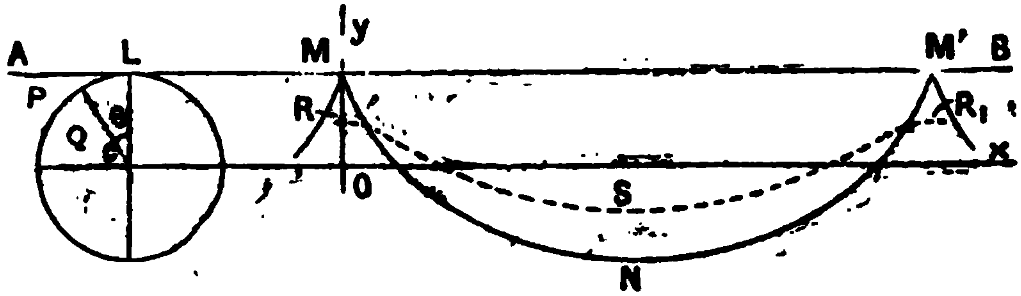
The cycloid meets the straight line AB at a series of cusps MM′ . . . , corresponding to the positions when the point P is vertically above the centre C of the rolling circle; on the trochoid these become 'crests' similar to those in the section of a wave-surface, which this curve is found closely to resemble; intermediate between M and M′ is the 'trough' S which has a smaller curvature than the 'crest'. With coordinates Ox, Oy, as shown, the equations to the cycloid is—

$x = R(\theta - \sin\theta)$, $y = R\cos\theta$, and to the trochoid is—

$x = R\,\theta - r\sin\theta$, $y = r\cos\theta$;

where θ is the angle POL, $R = PC$, and $r = QC$.

Fig. 11.



The curve described by a point on the circumference of a circle rolling on the exterior of another circle is termed an epicycloid; when rolling on the interior of the second circle it is termed a hypocycloid.

Evolutes and Involutes.

Definition.—If a curve be drawn passing through the centres of curvature at various points at a curve, the new curve is said to be the evolute of the original curve; conversely the original curve is termed the involute of the derived curve.

The involute of a curve is also derived by wrapping a thread around the circumference of the curve; the path described by a point on the thread as it is wound or unwound is the involute.

DIFFERENTIAL AND INTEGRAL CALCULUS.

Differential Calculus.

Definition.—A quantity is said to be a function of another when its value depends upon the value of the other.

Thus, x^2, $\sin x$, e^x are functions of x; xy is a function x and of y; and so on. A function of x is denoted by $f(x)$. The differential coefficient of a function (y) with respect to a variable (x) is the rate of increase of y corresponding to an indefinitely small increment of x. It is denoted by $\frac{dy}{dx}$ or $f'(x)$.

Thus, the speed of a ship is the differential coefficient of the distance travelled with respect to the time occupied.

Values of the differential coefficients with respect to x of some functions of x are given in the table below:—

y or $f(x)$	$\frac{dy}{dx}$ or $f'(x)$	y or $f(x)$	$\frac{dy}{dx}$ or $f'(x)$
x^n	nx^{n-1}	a^x	$a^x \log_e a$
uv	$u\frac{dv}{dx}+v\frac{du}{dx}$	$\frac{u}{v}$	$\frac{v\frac{du}{dx}-u\frac{dv}{dx}}{v^2}$
$\sin x$	$\cos x$	$\sinh x$	$\cosh x$
$\cos x$	$-\sin x$	$\cosh x$	$\sinh x$
$\tan x$	$\sec^2 x$	$\tanh x$	$\operatorname{sech}^2 x$
$\cot x$	$-\operatorname{cosec}^2 x$	$\coth x$	$-\operatorname{cosech}^2 x$
$\sec x$	$\sec x \cdot \tan x$	$\operatorname{sech} x$	$-\operatorname{sech} x \cdot \tanh x$
$\operatorname{cosec} x$	$-\operatorname{cosec} x \cdot \cot x$	$\operatorname{cosech} x$	$-\operatorname{cosech} x \cdot \coth x$
		$\log_e x$	$\frac{1}{x}$
$f(u)$	$\frac{du}{dx}\times\frac{df(u)}{du}$	$\sinh^{-1}x$ or $\log(x+\sqrt{x^2+1})$	$\frac{1}{\sqrt{x^2+1}}$
$\sin^{-1}x$ or $-\cos^{-1}x$	$\frac{1}{\sqrt{1-x^2}}$	$\cosh^{-1}x$ or $\log(x+\sqrt{x^2-1})$	$\frac{1}{\sqrt{x^2-1}}$
$\tan^{-1}x$ or $-\cot^{-1}x$	$\frac{1}{1+x^2}$	$\tanh^{-1}x$ or $\frac{1}{2}\log\frac{1+x}{1-x}$	$\frac{1}{1-x^2}$
$\sec^{-1}x$ or $-\operatorname{cosec}^{-1}x$	$\frac{1}{x\sqrt{x^2-1}}$	$\coth^{-1}x$ or $\frac{1}{2}\log\frac{x+1}{x-1}$	$\frac{1}{1-x^2}$
$\operatorname{vers}^{-1}x$ or $-\operatorname{covers}^{-1}x$	$\frac{1}{\sqrt{2x-x^2}}$		

Note.—The differential coefficient of $\frac{dy}{dx}$ with respect to x is denoted $\frac{d^2y}{dx^2}$, and is termed the second differential coefficient of y.

Application to Curves.

The equation of the tangent at a point (x, y) on a curve is $Y-y=\frac{dy}{dx}(X-x)$.

That of the normal to the curve is $X-x+(Y-y)\frac{dy}{dx}=0$.

The angle ϕ made by the tangent with the x axis, and the perimeter s measured from any fixed point on a curve are connected by—

$$\tan\phi = \frac{dy}{dx};\ \sin\phi = \frac{dy}{ds};\ \cos\phi = \frac{dx}{ds};\ \left(\frac{dx}{ds}\right)^2 + \left(\frac{dy}{ds}\right)^2 = 1.$$

The radius of curvature (ρ) at a point is given by—

$$\rho = \pm\frac{ds}{d\phi} = \pm\frac{\left(\frac{ds}{dx}\right)^3}{\frac{d^2y}{dx^2}} = \pm\frac{\left\{1+\left(\frac{dy}{dx}\right)^2\right\}^{3/2}}{\frac{d^2y}{dx^2}} = \pm\frac{\left\{1+\left(\frac{dx}{dy}\right)^2\right\}^{3/2}}{\frac{d^2x}{dy^2}}$$

When the curve is tangential to the x axis at the origin, then ρ is equal to $\frac{x^2}{2y}$ when x and y are very small.

INTEGRAL CALCULUS.

DEFINITION.—If y is the differential coefficient of a function z with respect to x, then, conversely, z is termed the integral of y with respect to x, being denoted $\int y\,dx$.

A table of integrals frequently required is appended.

y or $\frac{dz}{dx}$	z or $\int y\,.\,dx$	y or $\frac{dz}{dx}$	z or $\int y\,.\,dx$
x^n	$\frac{x^{n+1}}{n+1}$	$\frac{1}{x}$	$\log x$
a^x	$a^x/\log_e a$	e^x	e^x
$\cos x$	$\sin x$	$\sin x$	$-\cos x$
$\cot x$	$\log \sin x$	$\tan x$	$\log \sec x$
$\frac{1}{\sqrt{a^2-x^2}}$	$\sin^{-1}\frac{x}{a}$	$\frac{1}{a^2+x^2}$	$\frac{1}{a}\tan^{-1}\frac{x}{a}$
$\frac{1}{x\sqrt{x^2-a^2}}$	$\frac{1}{a}\sec^{-1}\frac{x}{a}$	$\frac{1}{\sqrt{2ax-x^2}}$	$\text{vers}^{-1}\frac{x}{a}$
$\frac{1}{\sqrt{x^2+a^2}}$	$\sinh^{-1}\frac{x}{a}$	$\frac{1}{\sqrt{x^2-a^2}}$	$\cosh^{-1}\frac{x}{a}$
$\sqrt{a^2-x^2}$	$\frac{x\sqrt{a^2-x^2}}{2}+\frac{a^2}{2}\sin^{-1}\frac{x}{a}$	$\sqrt{a^2+x^2}$	$\frac{x\sqrt{a^2+x^2}}{2}+\frac{a^2}{2}\sinh^{-1}\frac{x}{a}$
$\sqrt{x^2-a^2}$	$\frac{x\sqrt{x^2-a^2}}{2}-\frac{a^2}{2}\cosh^{-1}\frac{x}{a}$	$\text{cosec}\, x$	$\log\tan\frac{x}{2}$
$\sec x$	$\log\tan\left(\frac{\pi}{4}+\frac{x}{2}\right)$	$\frac{1}{x^2-a^2}$	$\frac{1}{2a}\log\frac{x-a}{x+a}$
$\frac{1}{a^2-x^2}$	$\frac{1}{2a}\log\frac{a+x}{a-x}$	$u\,.\,v$	$u\int v\,.\,dx-\int\left(\frac{du}{dx}\,.\int v\,.\,dx\right)dx$

Definite Integrals.—On evaluating the integral $\int y \,.\, dx$. if two constant quantities a and b are separately substituted for x, and the former result substracted from the latter, the difference is termed a definite integral between limits a and b, being denoted by $\int_a^b y \,.\, dx$. Thus $\int x^3 \,.\, dx = \frac{x^4}{4}$, and $\int_2^3 x^3\,dx = \frac{81-16}{4} = 16\frac{1}{4}$.

The following definite integrals are of frequent occurrence:—

$$\int_0^{\frac{\pi}{2}} \sin\theta \,.\, d\theta = 1 \qquad \int_0^{\frac{\pi}{2}} \cos\theta \,.\, d\theta = 1$$

$$\int_0^{\frac{\pi}{2}} \sin^2\theta \,.\, d\theta = \frac{\pi}{4} \qquad \int_0^{\frac{\pi}{2}} \cos^2\theta \,.\, d\theta = \frac{\pi}{4}$$

$$\int_0^{\frac{\pi}{2}} \sin^n\theta \,.\, d\theta = \int_0^{\frac{\pi}{2}} \cos^n\theta \,.\, d\theta = \frac{n-1}{n} \cdot \frac{n-3}{n-2} \quad \ldots \quad \frac{2}{3} \text{ when}$$

n is an odd integer.

$$= \frac{n-1}{n} \cdot \frac{n-3}{n-2} \quad \ldots \quad \frac{3}{4} \cdot \frac{1}{2} \cdot \frac{\pi}{2} \text{ when } n \text{ is an even integer.}$$

$$\int_0^{\frac{\pi}{2}} \sin^m\theta \,.\, \cos^n\theta \,.\, d\theta \ (m \text{ and } n \text{ being integral})$$

$$= \frac{(m-1)(m-3)\ \ldots\ (n-1)(n-3)\ \ldots}{(m+n)(m+n-2)(m+n-4)\ \ldots} \text{ when either } m \text{ or}$$

n is odd.

$$= \frac{(m-1)(m-3)\ \ldots\ (n-1)(n-3)\ \ldots}{(m+n)(m+n-2)(m+n-4)\ \ldots} \cdot \frac{\pi}{2} \text{ when } m \text{ and}$$

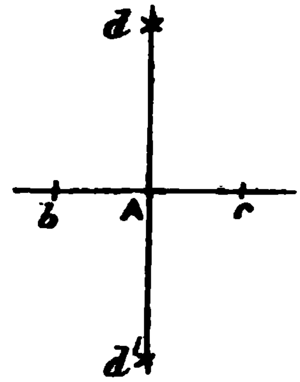
n are both even.

$$\int_0^{\infty} e^{-x^2} \,.\, dx = \tfrac{1}{2}\sqrt{\pi}.$$

PRACTICAL GEOMETRY.

1. *From any given point in a straight line to erect a perpendicular.* (Fig. 12.)

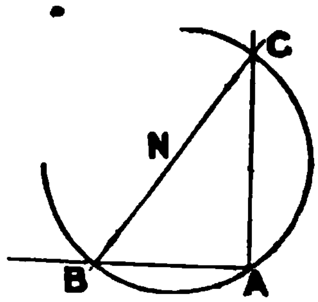
FIG. 12.



On each side of the point A in the line from which the perpendicular is to be erected set off equal distances A*b*, A*c*; and from *b* and *c* as centres, with any radius greater than A*b* or A*c*, describe arcs cutting each other at *d*, *d'*; a line drawn through *dd'* will pass through the point A, and A*d* will be perpendicular to *bc*.

2. *To erect a perpendicular at or near the end of a line.* (Fig. 13.)

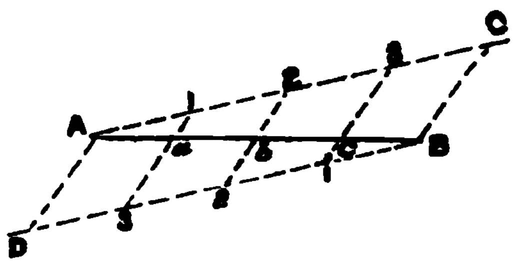
FIG. 13.



With any convenient radius, and at any distance from the given line AB, describe an arc, as BAC, cutting the given point in A; through the centre of the circle N draw the line BNC: a line drawn from the point A, cutting the intersection at C, will be the required perpendicular.

3. *To divide a line into any number of equal parts.* (Fig. 14.)

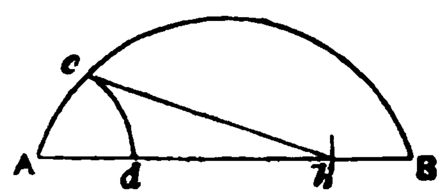
FIG. 14.



Let AB be the given straight line to be divided into a number of equal parts; through the points A and B draw two parallel lines AC and DB, forming any convenient angle with AB; upon AC and DB set off the number of equal parts required, as A–1, 1–2, &c., B–1, 1–2, &c.; join A and D, 1 and 3, 2 and 2, 3 and 1, C and B, cutting AB in *a*, *b*, and *c*, which will thus be divided into four equal parts.

4. *To find the length of any given arc of a circle.* (Fig. 15.)

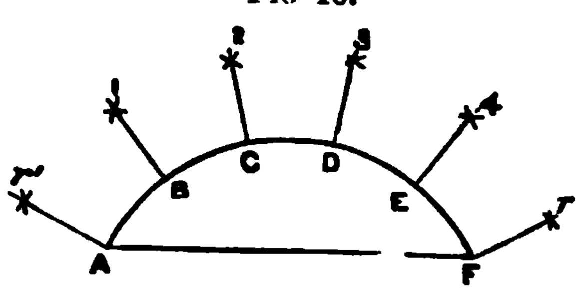
FIG. 15.



With the radius A*d*, equal to one-fourth of the length of the chord of the arc AB, and from A as a centre, cut the arc in *c*; also from B as a centre with the same radius cut the chord in *b*; draw the line *cb*, and twice the length of the line *cb* is the length of the arc nearly.

5. *To draw from or to the circumference of a circle lines tending towards the centre, when the centre is inaccessible.* (Fig. 16.)

FIG 16.

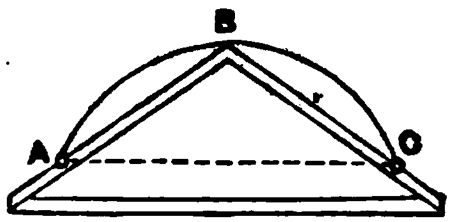


Divide the given portion of the circumference into the desired number of parts; then with any radius greater than the distance of two parts, describe arcs cutting each other as A1, C1, &c.;

draw the lines B1, C2, etc., which will lead to the centre, as required. *To draw the end lines* Ar', Fr, from B and E with the same radii as before describe the arc r', r, and with the radius B1. from A as centre, cut the former arcs at r', r; lines then drawn from Ar' and Fr will tend towards the centre, as required.

6. *To describe an arc of a circle of large radius.* (Fig. 17.)

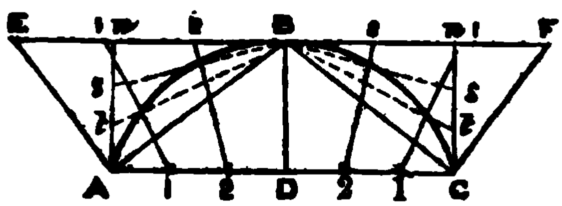
FIG. 17.



Let A, B, C be the three points through which the arc is to be drawn; join BA and BC; then construct a flat triangular mould, having two of its edges perfectly straight and making with each other an angle equal to ABC. Each of the edges should be a little longer than the chord AC. In the points A, C fix pins; and fix a pencil to the mould at B, and move the mould so as to keep its edges touching the pins at A and C, when the pencil will describe the required arc.

7. *Another method.* (Fig. 18.)

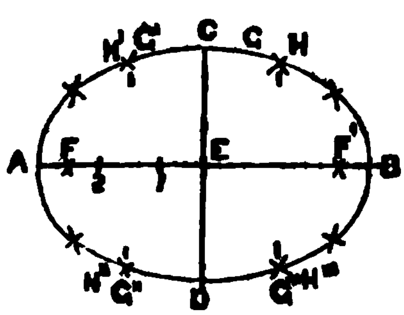
FIG. 18.



Draw the chord ADC, and draw EBF parallel to it; bisect the chord in D and draw DB perpendicular to AC; join AB and BC; draw AE perpendicular to AB and CF perpendicular to BC; also draw An and Cn perpendicular to AC; divide AC and EF into the same number of equal parts, and An, Cn into half that number of equal parts; join 1 and 1, 2 and 2, also B and s, s, and B, and t, t; through the points where they intersect describe a curve, which will be the arc required.

8. *To describe an ellipse, the major and minor axes being given.* (Fig. 19.)

FIG. 19.



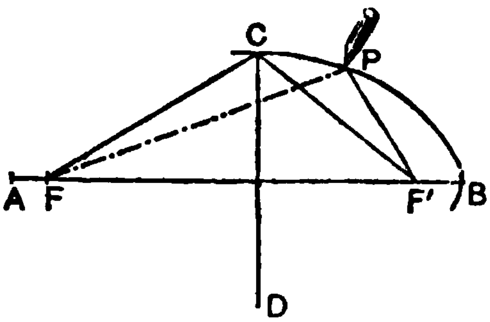
Let AB be the major and CD the minor axis, bisecting each other at right angles in the centre E; from C as a centre, with EA as radius, describe arcs cutting AB in F and F$'$, which will be the foci of the ellipse; between E and F set off any number of points, as 1, 2 (it is advisable that these points should be closer as they approach F).

From F and F$'$, with radius B1, describe the arcs G, G$'$, G$''$, G$'''$.

From F and F$'$, with radius A1, describe the arcs H, H$'$, H$''$, H$'''$, intersecting the arcs G, G$'$, G$''$, G$'''$ in the points I, I, I, I, which will be four points in the curve.

Then strike arcs from F, F$'$ first with A2, then with B2; these radii intersecting will give four more points. Proceed in this way with all the points between E and F; the curve of the ellipse must then be traced through these points by hand.

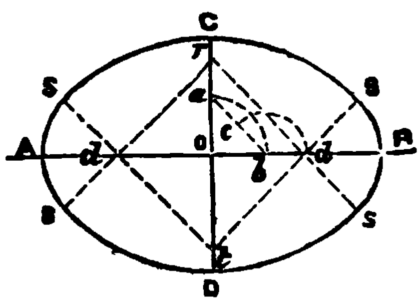
FIG. 20.



9. *Another method.* (Fig. 20.)

Let AB and CD be the axes; find F, F′, the two foci as before; join CF, CF′; make an endless thread equal in length to the perimeter of the triangle CFF′, and passing it round two drawing-pins at F and F′, draw it taut by means of a pencil-point P, so as to make a triangle PFF′ equal in perimeter to CFF′; move the pencil-point P along, keeping the thread taut, and the required curve will be described.

FIG. 21.



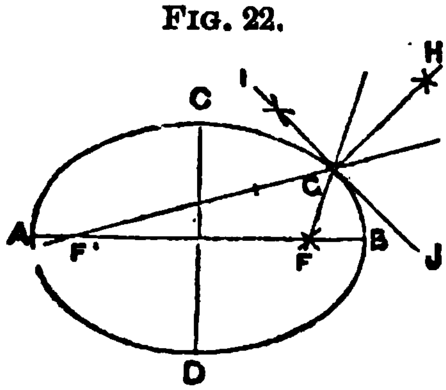
10. *Another method.* (Fig. 21.) (Approximate.)

At *o*, the intersection of the two diameters, as a centre, with a radius equal to the difference of the semi-diameters, describe the arc *ab*, and from *b* as a centre with half the chord *bca* describe the arc *cd*; from *o* as centre with the distance *od* cut the diameters in *dr*, *dt*; draw the lines *rs*, *rs*, *ts*, *ts*, then from *r* and *t* describe the arcs SDS, SCS; also from *d* and *d* describe the smaller arcs SAS, SBS, which will complete the ellipse required.

This method is applicable when the minor axis is at least ⅔ the major.

11. *To draw a tangent and a normal to an ellipse at any point.* (Fig. 22.)

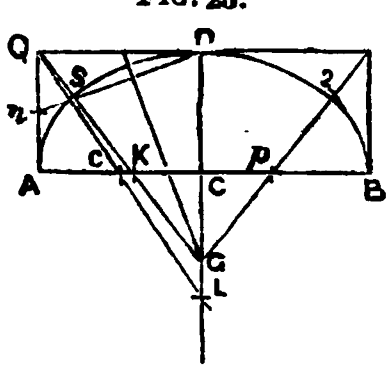
FIG. 22.



Let G be the point; from F, F′, the two foci of the ellipse, draw straight lines through G and produce them; bisect the angle made by the produced parts, by GH, then GH is normal to the curve; at G bisect the angle formed by FG and F′G produced, by IJ, then IJ will be the tangent to the curve at G.

12. *To describe an elliptic arc, the span and height being given.* (Fig. 23.) (Approximate.)

FIG. 23.

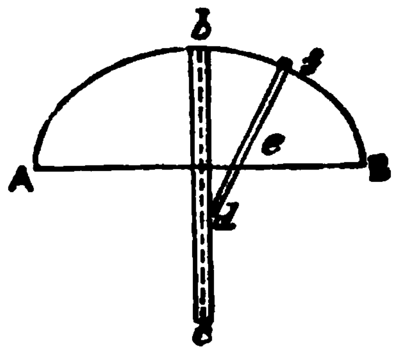


Bisect with a line at right angles the chord or span AB; erect the perpendicular AQ, and draw the line QD equal and parallel to AC; bisect AC in *c*, and AQ in *n*; make CL equal to CD, and draw the line L*c*Q; draw also the line *n*SD, and bisect SD with a line KG at right angles to it, and meeting the line LD in G; draw the line GKQ, and make C*p* equal to CK, and draw the line G*p*2; then from G as centre with the radius

GD describe the arc SD2, and from K and p as centres with the radius AK describe the arcs AS and 2B, which complete the arc, as required. This method gives good results for ellipses of all proportions.

13. *Another method.* (Fig. 24.)

FIG. 24.

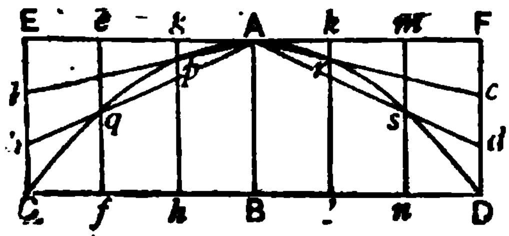


Bisect the major axis AB, and fix at right angles to it a straight guide, as bc; prepare of any material a rod or staff, def; at f fix a pencil or tracer so that df is one-half AB, and at E fix a pin so that ef is one-half the minor axis; move the staff, keeping its end d to the guide, and the pin e to AB, and the tracer will describe a half of the arc required.

14. *To describe a parabolic arc when its height and base are given.* (Fig. 25.)

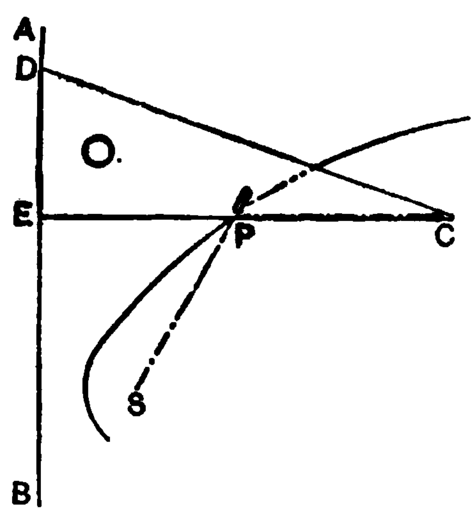
Let CD be the base and AB the height; set them off as shown in the figure, so that CB = CD, and complete the rectangle CDFE; divide EC and FD into any number of equal parts, say three, at a, b, c, and d; join Aa, Ab, Ac, Ad; divide AE, AF, BC, and BD into the same number of equal parts at e, g, k, m, f, h, l, n; join ef, gh, kl, mn, cutting Ab, Aa, Ac, Ad at q, p, r, and s. A line drawn through C q p A r s D will be the parabola required.

FIG. 25.



15. *Another method, when the directrix and focus are given.* (Fig. 26.)

FIG. 26.



Place a straight-edge to the directrix AB, and apply to it a square CDE; to the end C of the square fasten a thread, and pin the other end to S the focus, making the length of the thread equal to CE; slide the square along the straight-edge, holding the thread taut against the edge of the square by a pencil P, by which the curve is described.

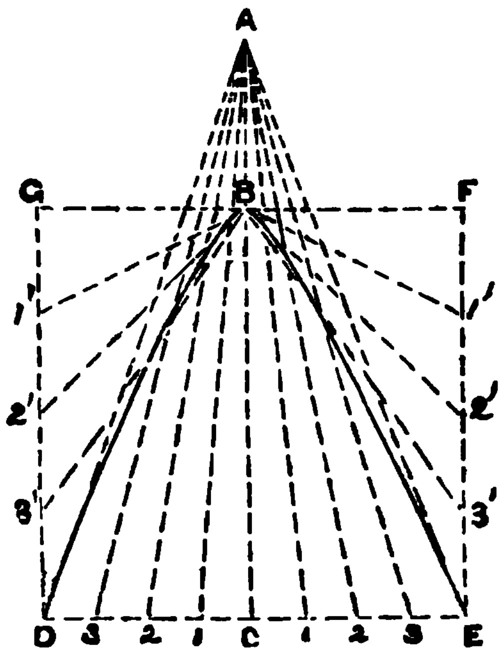
16. *To describe a hyperbola, the diameter, abscissa, and double ordinate being given.* (Fig. 27.)

Let AB be the diameter, BC its abscissa, and DE its double ordinate; then through B draw GF parallel and equal to DE; draw also DG and EF parallel to the abscissa BC.

Divide DC and CE into the same number of equal parts, as 1,2, &c., and from the points of division draw lines meeting in A.

Divide GD and EF each into the same number of parts as DC or CE, and from the points of division 1′, 2′, &c., draw lines meeting in B.

FIG 27.

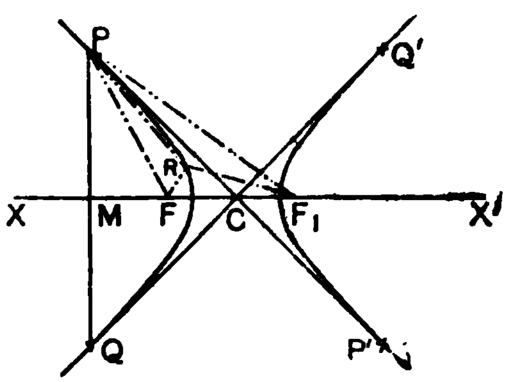


The points of intersection of the lines 1 and 1′, 2 and 2′, &c., thus found, will be points in the required curve.

17. *Another method, when the foci and a point on the curve are given.* (Fig. 28.)

A hyperbola is a curve such that the difference of the distances of any point in the curve from the two foci is equal to the transverse axis; and this property suggests the following mechanical construction:—

FIG. 28.



Let P (fig. 28) be any point on the curve, and F and F_1 its foci; join FF_1 and produce it, making XX′ the axis; draw PM perpendicular to XX′, and produce it to Q, making MQ equal to PM; bisect FF_1 at C, and produce PC, QC, to CP′, CQ′, making them equal to CP or CQ. The P, P′, Q, Q′ are four points on the curve. From one of them, say P, stretch two pieces of string PF and PF_1, fastening them to the paper at F and F_1, and simply knotting them at P; slip a small bead over them at P, and taking hold of P and keeping the thread taut, slide the bead along the threads, and the bead will describe the curve as far as the axis. Repeat this process at P′, Q, and Q′.

18. *To describe a rectangular hyperbola, given the asymptotes and a point on the curve.* (Fig. 29.)

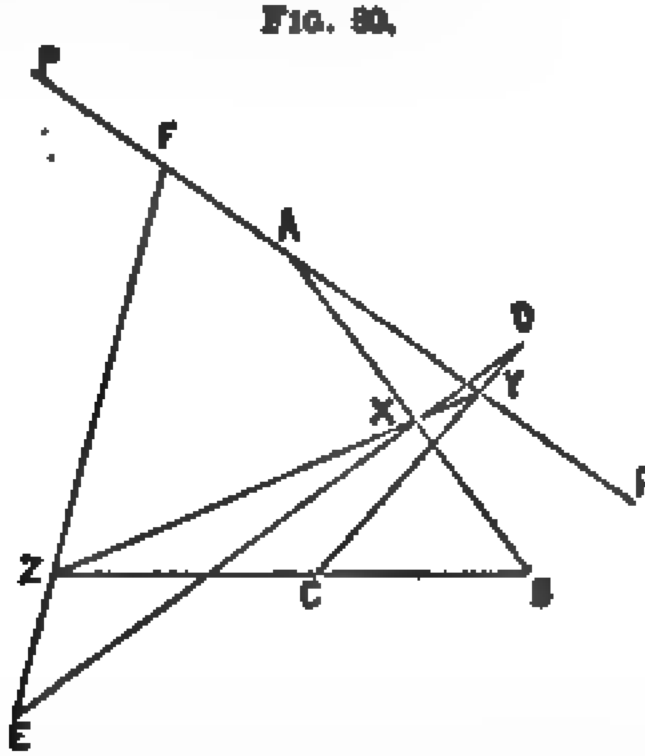
FIG. 29.

Let OX, OY be the asymptotes, and P the given point. Draw PM parallel to OY, and PS parallel to OX; set off any ordinates (generally equidistant for convenience) 11, 22, 33, 44, 55, 66, and join O to the intersections of these ordinates with PS, cutting PM at 1′, 2′, 3′, etc.; through 1′ draw 1′I parallel to OX, cutting 11 in I; through 2′, 2′II cutting 22 in II, and so on for III, IV, V, and VI; then P, I, II, III, etc., are points on the required curve.

19. *Given five points on any conic to obtain any number of additional points desired.* (Fig. 30.)

Denote the given points by A, B, C, D, E. Draw any line PAP′ through A, on which it is required to find a sixth point.

FIG. 30.



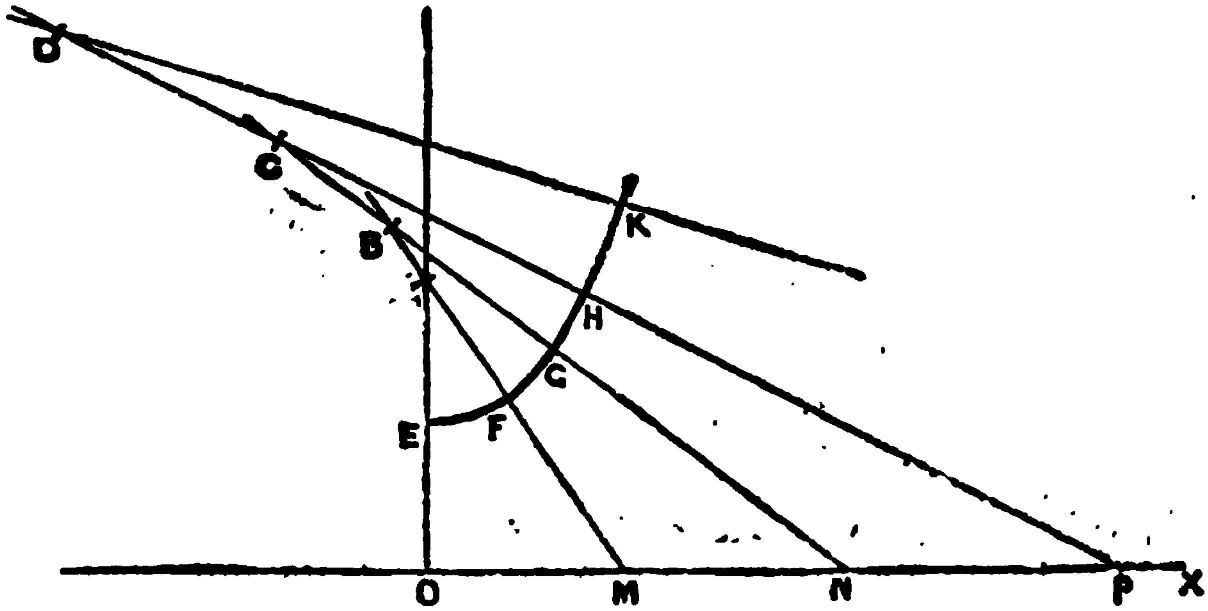
Join AB, DE, cutting at X, and CD cutting PAP′ at Y. Join BC, cutting XY in Z; join EZ, cutting PAP′ in F. F is the required point on the curve; by drawing additional lines through A, any number of points on the curve may be obtained.

20. *To construct a catenary approximately.* (Fig. 30A.)

Let B be the lowest point in the curve, OB its parameter, and OX its directrix. Make AB equal to OB; then with A as

centre and AE as radius describe the small arc EF. Join FA and produce it to M and to B, making BF equal to FM; then with B as centre and BF as radius describe the small arc FG.

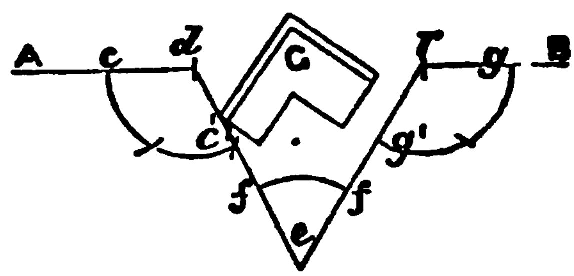
FIG. 30A.



Join BG and produce it to N and to C, making CG equal to GN; then with C as centre and CG as radius describe the small arc GH. Proceed in a similar manner till the curve is of the required length.

21. *To obtain by measurement the length of any direct line, though intercepted by some material object.* (Fig. 31.)

FIG. 31.



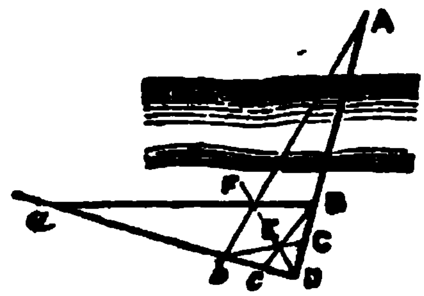
Suppose the distance between A and B is required, but the straight line is intercepted by the object G. On the point *d*, with any convenient radius, describe the arc *cc′*, and make the arc twice the radius *dc* in length; through *c′* draw the line *dc′e*, and on *e* describe another arc *ff* equal in length to the radius *dc*; draw the line *efr* equal to *efd*; from *r* describe the arc *g′g*, equal in length to twice the radius *rg*; continue the line through *rg* to B: then A and B will make a right line, and *de* or *er* will equal the distance between *dr*, by which the distance between AB is obtained, as required.

22. *To ascertain the distance geometrically of an inaccessible object on a level plane.* (Fig. 32.)

Let it be required to find the distance between A and B, A being inaccessible. Produce AB to any point D, and

bisect BD in C; through D draw Da, making any angle with DA, and take DC and DB respectively and set them off on Da as Db and Dc; join Bc, Cb, and Ab; through E, the intersection of Bc and Cb, draw DEF meeting Ab in F; join BF and produce it till it meets Da in a: then ab will be equal to AB, the distance required.

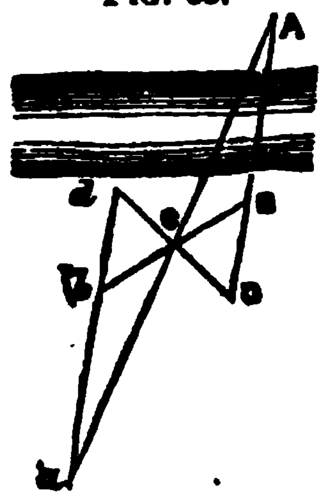
FIG. 32.



23. *Another method.* (Fig. 33.)

Produce AB to any point D; draw the line Dd at any angle to the line AB; bisect the line Dd in C, through which draw the line Bb, and make Cb equal to BC; join AC and db, and produce them till they meet at a: then ba will equal BA, the distance required.

FIG. 33.

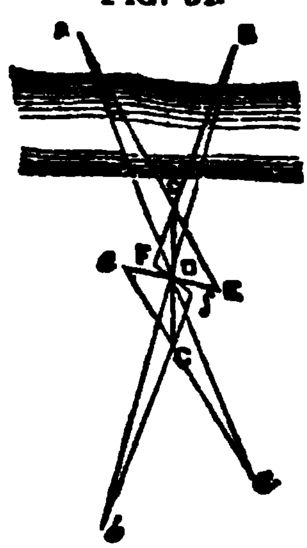


24. *To measure the distance between two objects, both being inaccessible.* (Fig. 34.)

Let it be required to find the distance between the points A and B, both being inaccessible. From any point C draw any line Cc, and bisect it in D; produce Ac and Bc, and prolong them to E and F; take the point E in the prolongation of Ac, and draw the line EDe, making De equal to DE.

In like manner take the point F in the prolongation of Bc, and make Df equal to DF; produce AD and eC till they meet in a, and also produce BD and fC till they meet in b: then the distance between the points a and b equals the distance between the inaccessible points A and B.

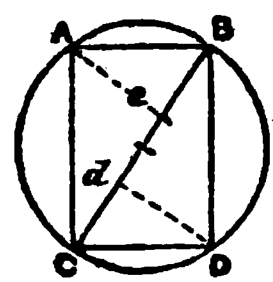
FIG. 34.



25. *To cut a beam of the strongest section from any round piece of timber.* (Fig. 35.)

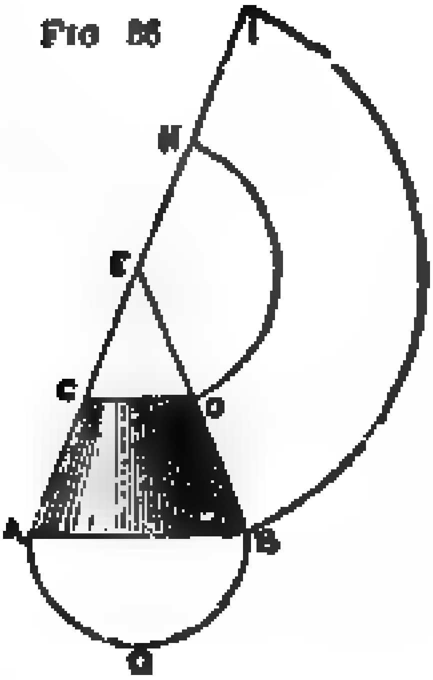
Divide any diameter CB of the circle into three equal parts; from d or e, the two points of division in CB, erect a perpendicular cutting the circumference of the circle in D or A; draw CD and DB, also AC equal to DB and AB equal to CD: the rectangle ABCD will be the section of the beam required.

FIG. 35.



Note.—To get the *stiffest* beam make $Cd = \frac{1}{4}$ CB and proceed as before.

FIG 36



26. *To describe the proper form of a flat plate by which to construct any given frustum of a cone.* (Fig. 36.)

Let ABCD represent the required frustum of a cone; continue the lines AC and BD till they meet in E; from E as a centre, with ED as radius, describe the arc DH, and from the same centre, with EB as radius, describe the arc BI; make BI equal in length to twice AGB, equal to the circumference of the base of the cone, draw the line EI: then BDHI is the form of the plate required.

27. *To find the development of the frustum of a right cone when cut by an angle inclined to the base.* (Fig. 37.)

FIG. 37.

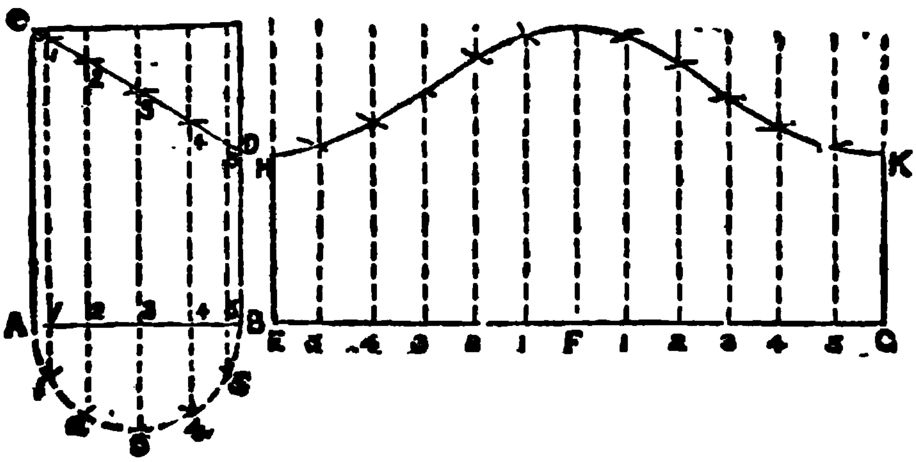
Let ABCD represent the required frustum of the cone; continue the lines AC and BD till they meet at E; divide the circumference of the base of the cone into any number of equal parts—say 12—in the points 1, 2, 3, etc.; join the projections of these points to E; next find the development of the base of the cone, as shown in the preceding example, and on it set off the same number of points—viz. 12—and draw lines from them to E; project the points of intersection of each of the lines E1, E2, E3, etc., with the line CD, horizontally on to either of the slant sides (say EB); then from E as centre measure the distance down along EB to the foot of each projection and set it off on the corresponding numbers (measuring from E) in the development: a line drawn through these points will give the curve of the top of the section, as required.

28. *To find the development of the frustum of a cylinder when cut by a plane inclined to the base.* (Fig. 38.)

Let ABCD represent the required frustum of a cylinder; divide the base into any number of equal parts—say 12—

and draw lines through those points on the cylinder parallel to AC and BD; draw a line EFG equal in length to the circumference of the cylinder, and divide it into the same number of parts; on each point of division set up perpendiculars to

FIG. 38.



it, making EH and GK equal in length to BD, and make FI equal in length to AC; then take the height at 1 and set it up on the corresponding number on each side of FI, and so on with each number: a line traced through the points thus obtained will be the curve of the required development.

29. *To find the approximate development of any given portion of a segment of a sphere.* (Figs. 39, 40, and 41.)

FIG. 41. FIG. 39.

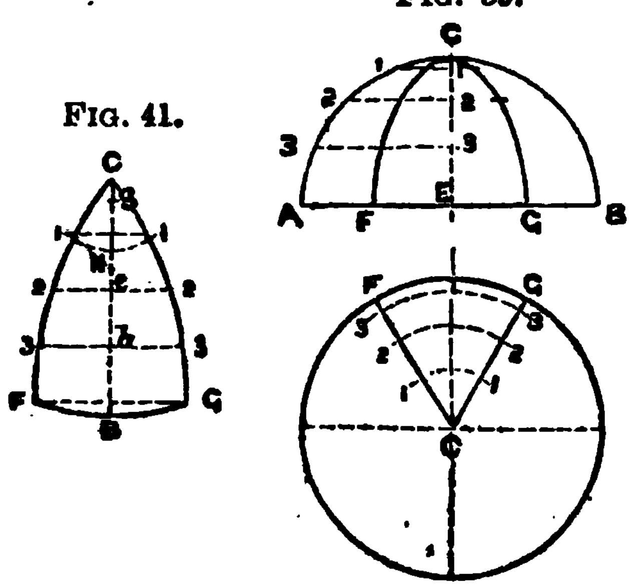


FIG. 40.

Let ABC (fig. 39) be the middle section of the segment, and CFG in the plan (fig. 40) the portion to be developed; bisect AB (fig. 39) in E, and set up the perpendicular EC; divide the arc AC into any given number of equal parts—say, four—and through the points of division draw the lines 1 1, 2 2, etc., parallel to AB; on the plan (fig. 40) from C as a centre, with the radius 1 1 taken from fig. 39, draw the arcs 1 1 cutting FC and CG in 1 and 1, and so on with 2 2 and 3 3; draw any line BC (fig. 41), making it equal in length to BC (fig. 39), and on it set off the same number of equal parts; at each point of division draw lines perpendicular to BC, and number them the same as on fig. 39.

Measure the length of the arc 1 1 in fig. 40, and set off half of it on each side of BC on line 1 1, and so on with each arc, including FG ; a line traced through the points thus obtained will give the curve of the sides of the given portion of the segment when it is developed. To describe the curve at the bottom of the figure, take one-fourth of the circumference of the base as a radius, and from F and G as centres describe arcs cutting BC in S ; then from S as centre, with the same radius, describe the arc FBG, which will be the curve of the bottom of the figure, as required.

Should the top of the figure be cut off at the line 1 1 (fig. 39), from S as a centre in fig. 41 describe the arc 1H1, which will be the curve of the top of the figure, as required.

30. *To find the approximate development of any given portion of a paraboloid.* (Figs. 42, 43, and 44.)

FIG. 42.

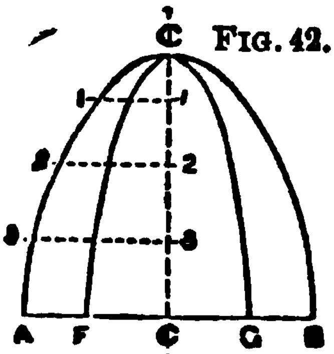


FIG 44.

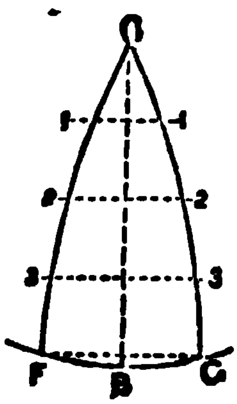
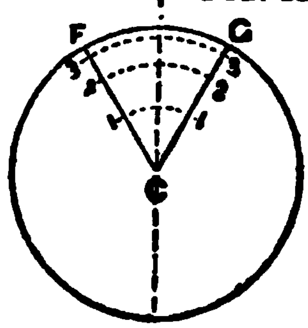


FIG. 43.



The development is found in the same manner as that of a portion of a segment of a sphere, as described in the last example (No. 29), with but one exception—that is, the length of the radius for describing the bottom curve of the figure, which instead of being equal to one-fourth of the circumference, as in example No. 29, is equal to one-half the length of the arc ACB (fig. 42) in this example.

31. *To find the development of an entablature plate.*

Let fig. 45 be the side elevation, fig. 46 the front elevation, fig. 47 the plan, and fig. 48 the development of the figure ; divide ADC (fig. 46) into eight equal parts, and from the points of intersection draw lines parallel to ABC, cutting CD (fig. 45) in the points 1, 2, etc.; on BD (fig. 45) erect a perpendicular EC, and from the points on CD draw lines parallel to BED. From fig. 46 take the points 1, 2, etc., on ABC and set them off on AFC (fig. 47), and erect perpendiculars from AFC at these points. From C (fig. 45) along CE measure the points C, 1, C, 2, etc., and set them off on their corresponding lines from AFC in fig. 47; draw a line through those points, then measure it with its divisions and set it off in fig. 48 as a straight line

AEC, and at the points of division erect perpendiculars, continuing them either side of the line AEC; measure the distances 1, 1; 2, 2, etc. (fig. 45), on either side of CE, and set them off

FIG. 45.

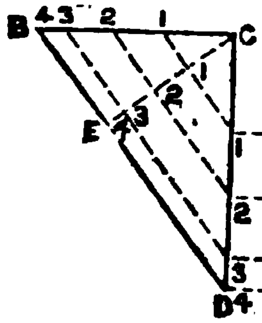


FIG. 46.

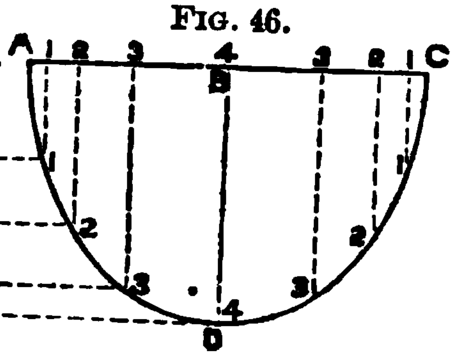


FIG. 47.

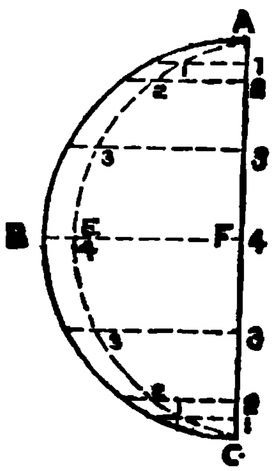
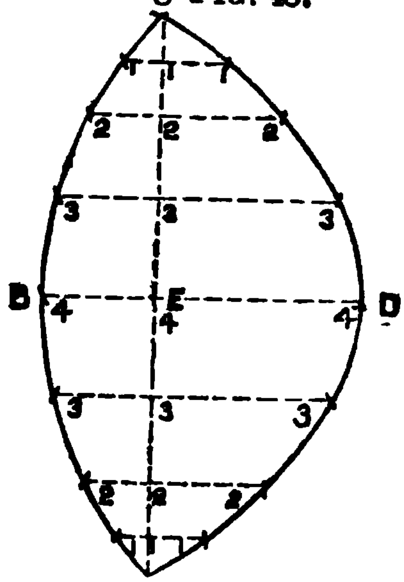


FIG. 48.

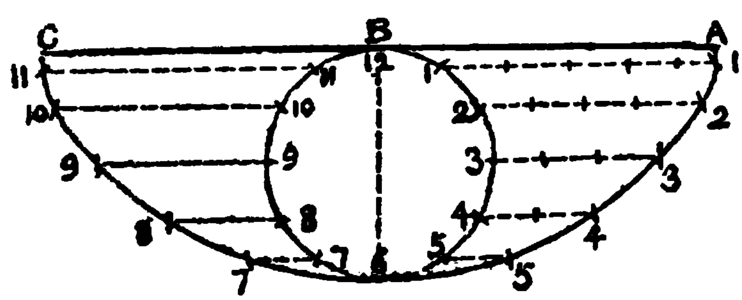


from AEC (fig. 48) on their corresponding lines, and on their respective sides of AEC. These will give the development.

32. *To describe a cycloid, the generating circle being given.* (Fig. 49.)

Let B6 be the generating circle; draw a line ABC, equal to the circumference of the generating circle, by dividing the circle into any number of given parts, as 1, 2, 3, etc., and

FIG. 49.



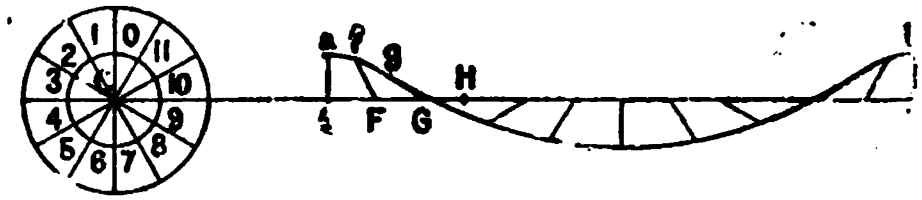
setting off half that number of parts on each side of B; draw lines from the intersections of the circle 1, 2, 3, etc., 7, 8, 9,

etc., parallel to AO ; set off one division of the circle outwards on the first lines 5 and 7, two divisions on the next lines 4 and 8, then three on the next, and so on : then the intersection of those points on the lines 1, 2, 3, etc., will be points in the curve.

33. *To draw a trochoid or wave-form, the height and length being given.* (Fig. 50.)

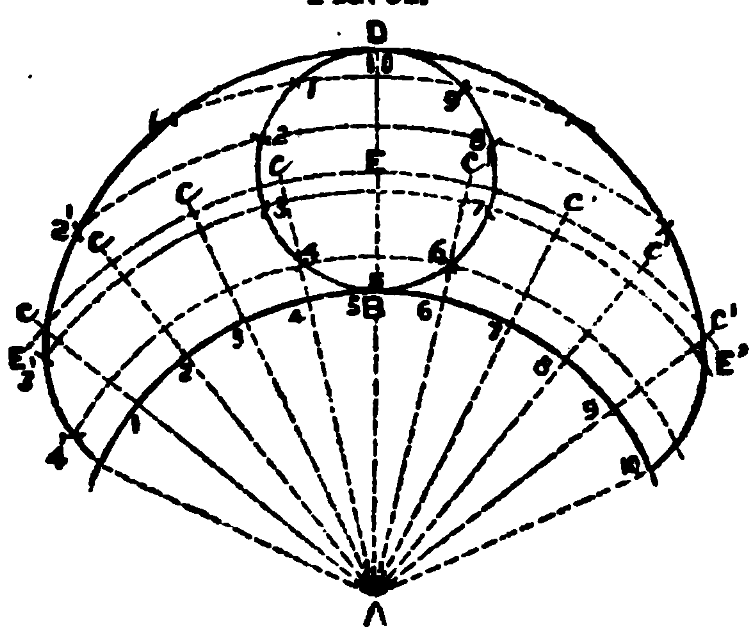
Draw AB equal to the length ; with centre C on AB produced describe a circle whose diameter is equal to the height. Divide the circumference into a convenient number (say 12) of equal parts 0, 1, 2, 3, . . . , CO being vertical. Divide AB into the same number of equal parts F, G, H, . . . From A, F, G, . . . B, draw A*a*, F*f*, G*g*, . . . B*b*, parallel and equal C 0, C 1, C 2, . . . C 0, respectively. A curve drawn through the points *a*, *f*, *g*, . . . *b* is the required trochoid.

FIG. 50.



34. *To describe an epicycloid, the generating circle and the directing circle being given.* (Fig. 51.)

FIG. 51.



Let BD be the generating circle, and AB the directing circle; divide the generating circle into any number of equal parts (say 10) as 1, 2, 3, etc., and set off the same distances round the directing circle; draw radial lines from A through these last points, and produce them to an arc drawn with A as centre and AE as radius, as shown by *cccc* and *c′c′c′c′* on the diagram; draw

concentric arcs also through all the points on the generating circle, with A as centre; then taking c, c, c, c and c', c', c', c' as centres, and BE as radius, describe arcs cutting the concentric circles at $1'$, $2'$, etc.: the points thus found will be points in the required curve.

35. *To describe a hypocycloid, the generating circle and the directing circle being given.* (Fig. 52.)

Proceed as in the epicycloid, the exception being that the construction lines are drawn within the directing circle instead of outside, as in the epicycloid.

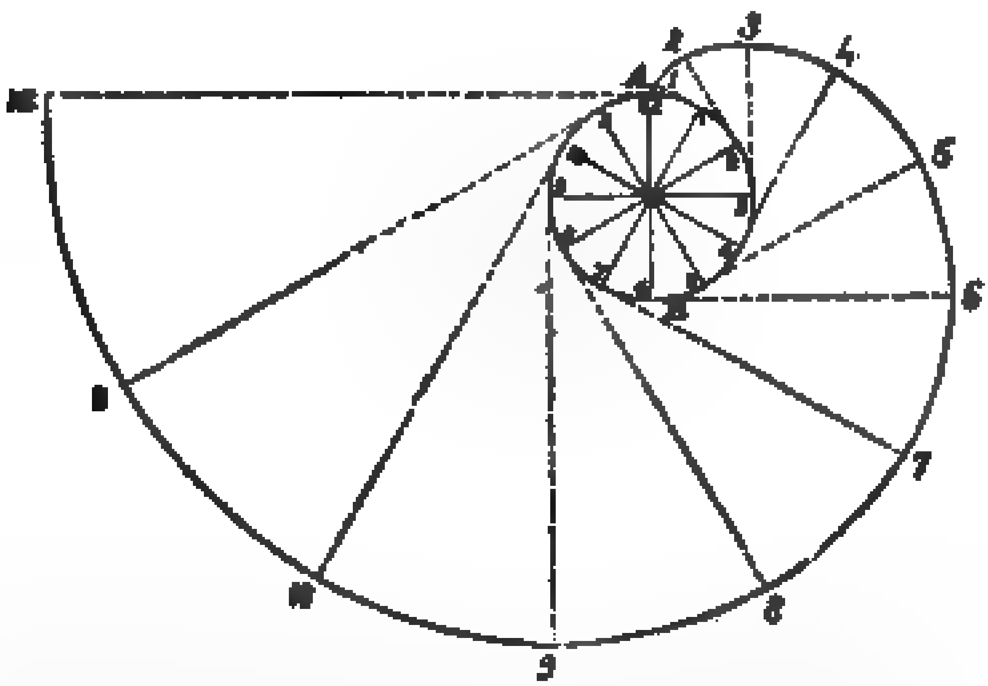
FIG. 52.

A

36. *To describe the involute of a circle.* (Fig. 53.)

Let AB be the given circle, which divide into any equal number of parts (say 12) as 1, 2, 3, etc.; from the centre draw radii to these points; then draw lines (tangents) at right angles to these radii. On the tangent to radius No. 1 set off from the circle a distance equal to one part, and on each of the

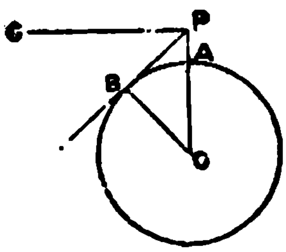
FIG. 53.



tangents set off the number of parts corresponding to the number of its radius, so that No. 12 has twelve divisions set off on it (that is, equal to the circumference of the circle): a line traced through the ends of these lines will be the curve required.

37. *To find the dip of the horizon.* (Fig. 53A.)

FIG. 53A.



Let O denote the centre of the earth, PB a tangent from the eye of an observer looking from a height AP to the earth's surface at B; then B is a point on the horizon: draw PC at right angles to PO; then the angle BPC is called the dip of the horizon.

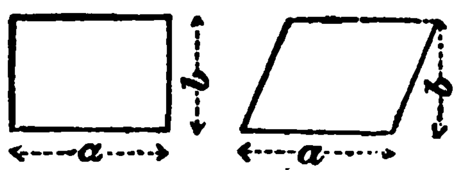
Let OP cut the earth's surface at A, and let the angle BPC be denoted by θ; with distances in miles, PB $= \sqrt{2 \,.\, \text{AP} \,.\, \text{AO}}$ approximately $= \sqrt{8{,}000 \times \text{AP}}$; and θ in degrees $= 1{\cdot}28 \sqrt{\text{AP}}$.

MENSURATION.

I. MENSURATION OF AREAS AND PERIMETERS.

1. *To find the area of any parallelogram.* (Fig. 54.)

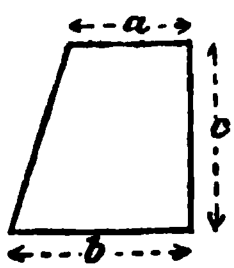
FIG. 54.



RULE.—Multiply the length by the perpendicular height, and the product will be the area. Thus, if A = the area, a = the length, and b = the perpendicular height, then A $= ab$.

2. *To find the area of a trapezoid.* (Fig. 55.)

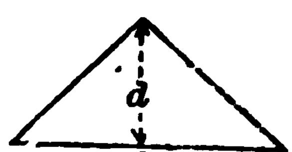
FIG. 55.



RULE.—Multiply the sum of the parallel sides by the perpendicular distance between them; half the product will be the area. Thus, if A = the area, b and a = the parallel sides, and c = the perpendicular distance between them, then A $= \dfrac{(a + b)c}{2}$

3. *To find the area of any triangle.* (Fig. 56.)

FIG. 56.

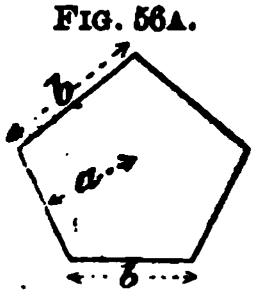


RULE.—Multiply the base by the perpendicular height; half the product will be the area. Thus, if A = the area, b = the base, and d = the perpendicular height, then A $= \dfrac{db}{2}$

4. Or, if the lengths of the 3 sides a, b, and c are given, then A $= \sqrt{s\,(s-a)\,(s-b)\,(s-c)}$ where $2s = a + b + c$.

5. *To find the area of any regular polygon.* (Fig. 56A.)

FIG. 56A.



RULE.—Multiply the sum of its sides by a perpendicular drawn from the centre of the polygon to one of its sides; half the product will be the area. Thus if A = the area, c = the number of sides, b = the length of one side, and a = the perpendicular, then A $= \dfrac{abc}{2}$

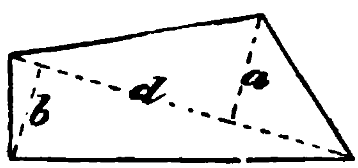
Table of Regular Polygons.

A = the angle contained between any two sides.
R = the radius of the circumscribed circle.
r = the radius of the inscribed circle.
S = the side of the polygon.

No. of Sides	Name	A	R=S×	r=S×	S=R×	S=r×	Area=S^2×
3	Trigon .	60°	·57735	·28868	1·73205	3·46410	·43301
4	Tetragon .	90°	·70711	·50000	1·41421	2·00000	1·00000
5	Pentagon .	108°	·85065	·68819	1·17557	1·45309	1·72048
6	Hexagon .	120°	1·00000	·86603	1·00000	1·15470	2·59808
7	Heptagon .	$128\frac{4}{7}$°	1·15238	1·03826	·86777	·96315	3·63391
8	Octagon .	135°	1·30656	1·20711	·76537	·82843	4·82843
9	Nonagon .	140°	1·46190	1·37374	·68404	·72794	6·18182
10	Decagon .	144°	1·61803	1·53884	·61803	·64984	7·69421
11	Undecagon	$147\frac{3}{11}$°	1·77473	1·70284	·56347	·58725	9·36564
12	Duodecagon	150°	1·93185	1·86603	·51764	·53590	11·19615

6. *To find the area of a quadrilateral.* (Fig. 57.)

Fig. 57.



Rule.—Multiply the diagonal d by the sum of the two perpendiculars a and b let fall upon it from the opposite angles; half the product will be the area. Thus if A = the area, a and b = the perpendiculars, and d = the diagonal, then

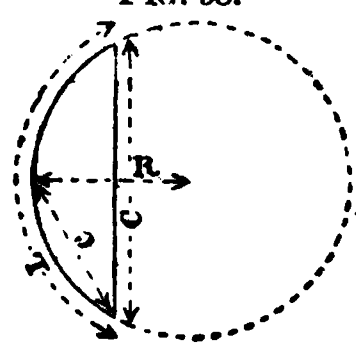
$$A = \frac{(a+b)\,d}{2}.$$

7. *To find the circumference of a circle, the diameter being given; or to find the diameter of a circle, the circumference being given.*

Rule.—Multiply the diameter by 3·1416, the product will be the circumference; or divide the circumference by 3·1416, the quotient will be the diameter.

8. *To find the length of any arc of a circle.* (Fig. 58.)

Fig. 58.



Rule (I).—From eight times the chord of half the arc subtract the chord of the whole arc; one-third of the remainder will be the length of the arc, nearly. Thus if L = length of the arc, C = chord of the whole arc, c = chord of half the arc, then

$$L = \frac{8c - C}{3}$$

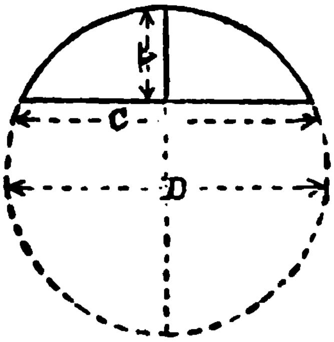
RULE (II).—The radius being known, multiply together the number of degrees in the arc, the radius, and the number ·01745; the product will be the length of the arc. Thus if L = length of the arc, D = degrees in the arc, R = radius, then

$$L = D \times R \times \cdot 01745.$$

RULE (III).—(*Applicable to any fairly flat curve.*) Add to the chord eight-thirds the square of the maximum height (or versed sine) divided by the chord. The sum is the length of the curve, very nearly. Thus if C = chord, and V = greatest height of arc above chord, length $= C + \frac{8}{3}\frac{V^2}{C}$

9. *To find the diameter of a circle, the chord and versed sine being given.* (Fig. 59.)

FIG. 59.

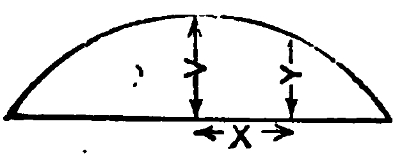


RULE.—Divide the square of half the chord by the versed sine, to the quotient add the versed sine, and the sum will be the diameter. Thus if D = the diameter, C = the chord, and V = the versed sine, then

$$D = \left\{\frac{\left(\frac{C}{2}\right)^2}{V} + V\right\}$$

10. *To find the length of any ordinate of a segment of a circle.* (Fig. 60.)

FIG. 60.



RULE.—Find the radius of the arc of the segment (if not given) by the preceding formula; and from the square root of the difference of the squares of the radius and distance of the ordinate from the centre of the segment, subtract the radius; and to the result add the height of the segment, and the sum will be the required ordinate. Thus if R = the radius, X = the distance of the ordinate from the centre of the segment, V = the height of the segment, and Y = the required ordinate, then

$$Y = \sqrt{R^2 - X^2} - R + V.$$

11. *To find the area of a circle.*

RULE (I).—Multiply the square of the diameter by ·7854, and the product will equal the area, nearly. Thus if A = the area, D = the diameter, then $A = D^2 \times \cdot 7854$.

RULE (II).—Multiply the square of the circumference by ·07958, and the product will be the area. Thus if A = area, C = circumference, then $A = C^2 \times \cdot 07958$.

Table of Properties of the Circle.

π	$= 3{\cdot}1415926535897932384 6$	$\sqrt{2}$	$= 1{\cdot}414213562373095048 80$
$\frac{\pi}{2}$	$= 1{\cdot}5707963267948966192 3$	$\sqrt{\frac{1}{2}}$	$= {\cdot}70710678118654752440$
$\frac{\pi}{4}$	$= {\cdot}7853981633974483096 2$	$2\sqrt{\pi}$	$= 3{\cdot}5449077018110320546 0$
$\frac{\pi}{6}$	$= {\cdot}5235987755982988730 8$	$2\sqrt{\frac{1}{\pi}}$	$= 1{\cdot}1283791670955125739 0$
$\pi\sqrt{2}$	$= 4{\cdot}4428829381583662470 2$	$\frac{1}{2}\sqrt{\pi}$	$= {\cdot}8862269254527580136 5$
$\pi\sqrt{\frac{1}{2}}$	$= 2{\cdot}2214414690791831235 1$	$\frac{1}{8}\sqrt{\frac{1}{\pi}}$	$= {\cdot}0705236979434695358 7$
$\sqrt{\pi}$	$= 1{\cdot}7724538509055160273 0$	2π	$= 6{\cdot}2831853071795864769 3$
$\sqrt{\frac{1}{\pi}}$	$= {\cdot}5641895835477562869 5$	$\frac{2}{\pi}$	$= {\cdot}6366197723675813430 8$

$\frac{\pi}{180} = {\cdot}01745$ $\qquad$ $\frac{180}{\pi} = 57{\cdot}3$

$\frac{1}{\pi} = {\cdot}3183$ $\qquad$ $\frac{60}{2\pi} = 9{\cdot}5493$

$\pi^2 = 9{\cdot}870$

In the following formulæ A = area, C = circumference, D = diameter, S = side of square.

Circumference	$= D \times \pi = R \times 2\pi = \sqrt{A} \times 2\sqrt{\pi}$
Diameter	$= C \times \frac{1}{\pi} = \sqrt{A} \times 2\sqrt{\frac{1}{\pi}}$
Radius	$= C \times \frac{1}{2\pi} = \sqrt{A} \times \sqrt{\frac{1}{\pi}}$
Area	$= R^2 \times \pi = D^2 \times \frac{\pi}{4} = \frac{1}{2} RC$
Side of equal square	$= R \times \sqrt{\pi} = D \times \frac{1}{2}\sqrt{\pi} = C \times \frac{1}{2}\sqrt{\frac{1}{\pi}}$
Side of inscribed square	$= D \times \sqrt{\frac{1}{2}} = C \times \frac{1}{\pi}\sqrt{\frac{1}{2}} = \sqrt{A} \times \sqrt{\frac{2}{\pi}}$
Diameter of equal circle	$= S \times 2\sqrt{\frac{1}{\pi}}$

Diameter of circumscribing circle $= S \times \sqrt{2}$

Circumference of circumscribing circle $= S \times \pi\sqrt{2}$

Circumference of equal circle $= S \times 2\sqrt{\pi}$

Area of inscribed square $= A \times \frac{2}{\pi}$

12. *To find the area of a sector of a circle.*

RULE (I.)—Multiply the length of the arc by the radius of the sector, and half the product will equal the area.
A = area of sector, L = length of arc, R = radius.

RULE (II).—Multiply the number of degrees in the arc by the area of the circle, and $\frac{1}{360}$ of the product will equal the area. Thus, if A = area, D = number of degrees in the arc. a = area of circle, then

$$A = \frac{Da}{360}$$

13. *To find the area of the segment of a circle.*

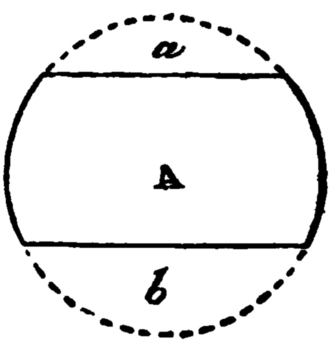
RULE (I).—Find the area of a sector having the same arc as the segment; then deduct the area of the triangle contained between the chord of the segment and the radii of the sector. The remainder will be the area of the segment. Thus, if A = the area of the segment, c = the chord, and H = the height, then

$$A = \frac{1}{2H^2}\left[\left\{\left(\frac{c}{2}\right)^2 + H^2\right\}^2 \tan^{-1}\frac{2H}{c} - \frac{cH}{2}\left\{\left(\frac{c}{2}\right)^2 - H^2\right\}\right]$$

RULE (II).—To two-thirds of the product of the chord and height of the segment, add the cube of the height divided by twice the chord; the sum will be the area of the segment, nearly. Thus,

$$A = \left(\frac{2cH}{3} + \frac{H^3}{2c}\right)$$

FIG. 61.



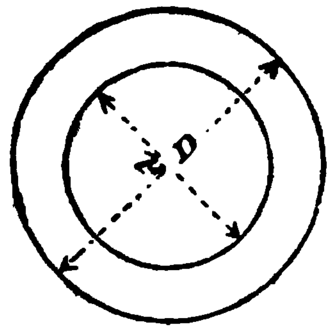
14. *To find the area of a circular zone.* (Fig. 61.)

RULE.—Find the area of the circle of which the zone forms a part, and from it subtract the sum of the two segments of the circle formed by the zone; the remainder will be the area. Thus, if A = area of the zone, a and b = the area of the two segments respectively, and C = area of the circle, then $A = C - (a + b)$.

15. *To find the area of a flat circular ring.* (Fig. 62.)

RULE.—Multiply the sum of the inside and outside diameters by their difference, and the result by ·7854;

FIG. 62.

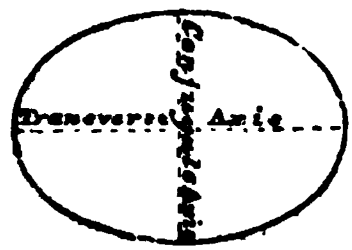


the product last obtained will be the area. Thus, if A = area of ring, D = diameter of large circle, and d = diameter of small circle, then

$$A = \cdot 7854\{(D+d)(D-d)\}$$

16. *To find the area of an ellipse.* (Fig. 63.)

FIG. 63.



RULE.—Multiply together the transverse and conjugate diameters of the ellipse, and the result by $\frac{\pi}{4}$ or $\cdot 7854$; the product will be the area. Thus, if A = area of ellipse, a = the conjugate diameter, and b = the transverse diameter, then

$$A = \cdot ab \times \cdot 7854.$$

17. *To find the area bounded by a rectangular hyperbola, two ordinates and the base.* (Fig. 8, p. 15.)

RULE.—Multiply the product of either ordinate and the corresponding abscissa by the hyperbolic logarithm of the ratio between the two abscissæ. Thus the area of ABCD is equal to $AB \times OB \times \log_e \frac{OC}{OB}$

18. *To find the area bounded by a cycloid and the line joining the cusps.* (Fig. 11, p. 18.)

RULE.—Multiply the area of its generating circle by 3; *or* multiply the product of its length and height by $\frac{3}{4}$.

19. *To find the area bounded by a trochoid and a line joining the crests.* (Fig. 50, p. 34.)

RULE.—If R be the radius of the rolling circle (or the length divided by 2π), and r the radius of the tracing circle (or one-half the height from crest to trough), the required area is equal to $\pi r(2R + r)$.

Note.—The area between the curve and the line joining the troughs is $\pi r(2R - r)$.

20. *To find the area of a segment of a parabola.*

RULE.—Multiply the base by $\frac{2}{3}$ of the maximum height.

21. *To find a general expression for the area of any plane curve.*

Using cartesian co-ordinates, the area intercepted between the curve, the x axis, and two ordinates distant a and b from the origin, is equal to the definite integral $\int_a^b y \, . \, dx$.

Using polar co-ordinates, the area intercepted between the curve and two radial lines making angles α and β with Ox, is equal to $\frac{1}{2} \int_\alpha^\beta r^2 \, . \, d\theta$.

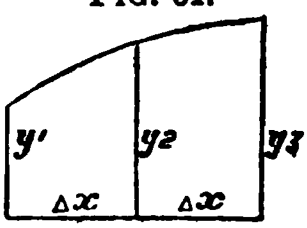
Remark.—A curve whose equation is given by

$$y = a + bx + cx^2 + dx^3 + \ . \ . \ . \ Kx^n$$

is said to be a parabolic curve of the n^{th} order. Thus a parabolic of the first order is a straight line; of the second order a common parabola. Rules for the area of a parabola of any order are applicable also to curves of a lower order, but not in general to those of a higher order.

22. *To find the area of a parabola of the third order when three ordinates are given.* (Fig. 64.)

FIG. 64.



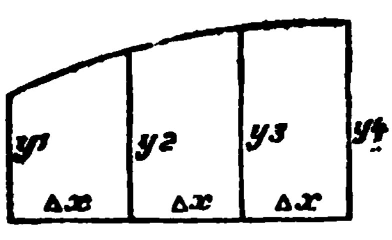
RULE.—To the sum of the two endmost ordinates add four times the intermediate ordinate; multiply the final sum by $\frac{1}{3}$ of the common interval between the ordinates. The result will be the area. Thus, if y_1, y_2, and y_3 be the ordinates, Δx the common interval, and $\int y dx$ the area, then

$$\int y dx = \frac{\Delta x}{2}(y_1 + 4y_2 + y_3).$$

Note.—This is termed Simpson's first rule.

23. *To find the area of a parabola of the third order when four ordinates are given.*

FIG. 65.



RULE.—To the sum of the two endmost ordinates add three times the intermediate ordinates; multiply the final sum by $\frac{3}{8}$ of the common interval between the ordinates: the result will be the area. Thus, if $\int y dx$ = the area, then

$$\int y dx = \frac{3\Delta x}{8}(y_1 + 3y_2 + 3y_3 + y_4).$$

Note.—This is termed Simpson's second rule.

TABLE SHOWING THE MULTIPLIERS FOR THE FOREGOING AND SOME OTHER RULES.

y_1, y_2, y_3, etc. = the ordinates, and Δx = the common interval or abscissa between the ordinates.

1. Trapezoidal rule.

$$\text{Area} = \frac{\Delta x}{2}(y_1 + y_2).$$

2. Rule for parabola of the third order with three ordinates.

$$\text{Area} = \frac{\Delta x}{3}(y_1 + 4y_2 + y_3). \quad \text{(Simpson's first rule.)}$$

3. Rule for parabola of the third order with four ordinates.

$$\text{Area} = \frac{3\Delta x}{8}(y_1 + 3y_2 + 3y_3 + y_4). \quad \text{(Simpson's second rule.)}$$

4. Rule for parabola of the fifth order with five ordinates.

$$\text{Area} = \frac{2\Delta x}{45}(7y_1 + 32y_2 + 12y_3 + 32y_4 + 7y_5).$$

5. Rule for parabola of the fifth order with six ordinates.

$$\text{Area} = \frac{5\Delta x}{288}(19y_1 + 75y_2 + 50y_3 + 50y_4 + 75y_5 + 19y_6).$$

6. Rule for parabola of the seventh order with seven ordinates.

$$\text{Area} = \frac{\Delta x}{140}(41y_1 + 216y_2 + 27y_3 + 272y_4 + 27y_5 + 216y_6 + 41y_7).$$

7. Approximation for curve with six ordinates.

$$\text{Area} = \frac{25\Delta x}{24}(0{\cdot}4y_1 + y_2 + y_3 + y_4 + y_5 + 0{\cdot}4y_6).$$

8. Weddle's approximation for curve with seven ordinates.

$$\text{Area} = \frac{3\Delta x}{10}(y_1 + 5y_2 + y_3 + 6y_4 + y_5 + 6y_6 + y_7).$$

24. *To measure any curvilinear area by means of the trapezoidal rule.*

RULE.—To the sum of half the two endmost ordinates add all the other ordinates, and multiply the sum by the common interval; the result will be the area. Thus,

$$\int y dx = \Delta x\left(\frac{y_1 + y_n}{2} + y_2 + y_3 \; . \; . \; . \; . + y_{n-1}\right)$$

Remark.—In shipbuilding work it is very often convenient to perform the additions in the above rule mechanically, by measuring off the ordinates continuously on a long strip of paper, and measuring the total length on the proper scale. This rule is only approximate, but it is especially useful for getting the areas of the transverse sections in the first rough calculations of trim, displacement, etc.

25. *To measure any curvilinear area by means of Simpson's first rule.*

RULE.—To the sum of the first and last ordinates add four times the intermediate ordinates and twice all the dividing

ordinates; multiply the final sum by $\frac{1}{3}$, the common interval: the result will be the area. Thus

$$\int y dx = \frac{\Delta x}{3}(y_1 + 4y_2 + 2y_3 + 4y_4 + 2y_5 \ldots + 4y_{n-1} + y_n).$$

Remark.—The number of intervals in this rule must be even. The ordinates which separate the parabolas into which the figure is conceived to be divided, are called dividing ordinates, and all the other ordinates except the two endmost ones are called intermediate ordinates.

26. *To measure any curvilinear area by means of Simpson's second rule.*

RULE.—To the sum of the two endmost ordinates add three times the intermediate ordinates and twice all the dividing ordinates; multiply the final sum by $\frac{3}{8}$, the common interval, and the result will be the area. Thus

$$\int y dx = \frac{3\Delta x}{8}(y_1 + 3y_2 + 3y_3 + 2y_4 + 3y_5 \ldots + 3y_{n-1} + y_n).$$

The number of intervals in this case must be a multiple of three.

Remark.—The sequence of the multipliers in the two foregoing rules is obvious. Thus in the first rule the simple multipliers are 1 . 4 . 1, but they are combined thus:—

```
1 . 4 . 1
        1 . 4 . 1
                1 . 4 . 1
                          . . . . . .
                                      1 . 4 . 1
                                              1 . 4 . 1
                                                      1 . 4 . 1
-----------------------------------------------------------------
1 . 4 . 2 . 4 . 2 . 4 . . . . . . . 4 . 2 . 4 . 2 . 4 . 1
```

In the second rule the multipliers are 1 . 3 . 3 . 1.

```
1 . 3 . 3 . 1
            1 . 3 . 3 . 1
                        1 . 3 . 3 . 1 . . . . .
                                                1 . 3   3 . 1
                                                            1 . 3 . 3 . 1
---------------------------------------------------------------------------
1 . 3 . 3 . 2 . 3 . 3 . 2 . 3 . 3 . . . . . . . . . . 3 . 3 . 2 . 3 . 3 . 1
```

And in the same way the multipliers to measure any curvilinear area may be obtained from the table on p. 43.

Simpson's first rule is superior to the second rule in accuracy as well as simplicity.

27. *To measure any curvilinear area when subdivided intervals are used.*

1st. *When Simpson's first rule is used.*

RULE.—Diminish the multiplier of each ordinate belonging to a set of subdivided intervals in the same proportion in which

the intervals are subdivided. Multiply each ordinate by its respective multiplier as thus found, and treat the sum of their products as if they were whole intervals; that is, multiply the sum thus found by ⅓ of a whole interval, and the product will be the area.

2nd. When Simpson's second rule is used.

RULE.—Proceed as in the first rule, but multiply by ⅜ of a whole interval for the area.

Example to Simpson's First Rule.—The series of multipliers for whole intervals being 1 . 4 . 2 . 4 . 2, &c., those for half-intervals will be ½, . 2 . 1 . 2 . 1, &c., and for quarter-intervals ¼ . 1 . ½ . 1 . ½, &c.

Remark.—When an ordinate stands between a larger and a smaller interval, its multiplier will be the sum of the two multipliers which it would have had as an end ordinate for each interval. Thus for an ordinate between a whole and a half interval the multiplier is $\frac{1}{2}+1=1\frac{1}{2}$, and between a half and a quarter interval $\frac{1}{2}+\frac{1}{4}=\frac{3}{4}$.

TABLE OF MULTIPLIERS WHEN SUBDIVIDED INTERVALS ARE USED.

Simpson's First Rule.

Ordinates	0	1	2	2⅓	2⅔	3	3⅓	3⅔	4	5	6	6½	7	7½	8
Multipliers	1	4	1⅓	1⅓	⅔	1⅓	⅔	1⅓	1⅓	4	1½	2	1	2	½
Ordinates	0	½	1	1½	2	2½	3	4	5	5½	6	6¼	6½	6¾	7
Multipliers	½	2	1	2	1	2	1½	4	1½	2	¾	1	½	1	¼
Ordinates	0	1	2	2½	3	3¼	3½	3¾	4	4⅙	4⅓	4½	4⅔	4⅚	5
Multipliers	1	4	1½	2	¾	1	½	1	5/12	⅔	⅓	⅔	⅓	⅔	⅙

Simpson's Second Rule.

Ordinates	0	1	2	3	3½	4	4½	5	5½	6	6⅙	6⅓	6½	6⅔	6⅚	7
Multipliers	1	3	3	1½	1½	1½	1	1½	1½	⅚	½	½	⅓	½	½	⅙
Ordinates	0	⅓	⅔	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3¼	3½	3¾	4
Multipliers	⅓	1	1	7/12	¾	¾	½	¾	¾	½	¾	¾	½	¾	¾	¼
Ordinates	0	½	1	1½	2	2½	3	3⅓	3⅔	4	4⅙	4⅓	4½	4⅔	4⅚	5
Multipliers	½	1½	1½	1	1½	1½	⅚	1	1	½	½	½	⅓	½	½	⅙

Note.—The ordinates in this table are numbered the same as if they were the number of intervals from the origin.

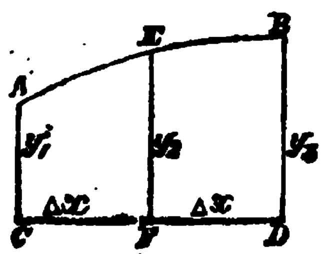
Thomson's Rule may be used when subdivided intervals are used at each end; the advantage being that all multipliers except the three end ones are unity; so also in the common multiplier. Thus the ordinates should be multiplied by $\frac{1}{4}$, $\frac{1}{3}$, $1\frac{1}{12}$, 1, 1, 1, ..., 1, 1, $1\frac{1}{12}$, $\frac{1}{3}$, $\frac{1}{4}$; the spacing of the three ordinates at each end being one half that elsewhere.

28. *To calculate the area separately of one of the two divisions of a parabolic figure of the second order.* (Fig. 66.)

RULE.—To eight times the middle ordinate add five times the near end ordinate, and subtract the far end ordinate; multiply the remainder by $\frac{1}{12}$ the common interval: the result will be the area.

Note.—The near end ordinate is the ordinate at the end of the division of which the area is to found.

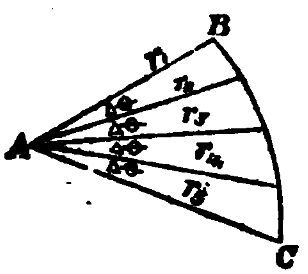
FIG. 66.



Ex.: In figure ABCD let it be required to find the area of the division ACEF. Let y_1 = the near end ordinate, y_2 = the middle ordinate, and y_3 = the far end ordinate; then $\int y\,dx = \frac{\Delta x}{12}(5y_1 + 8y_2 - y_3)$.

29. *To measure an area bounded by an arc of a plane curve and two radii.* (Fig. 67.)

FIG. 67.



RULE.—Divide the angle subtended by the arc into any number of equal angular intervals by means of radii. Measure these radii and compute their half-squares. Treat those half-squares as if they were ordinates of a curve by Simpson's first or second rule, as the number of intervals may require.

Note.—The common interval must be taken in circular measure. (See pp. 8 and 9.)

Ex.: In the figure ABC let r_1, r_2, r_3, r_4, r_5 = the radii, $\Delta\theta$ = the common angular interval, and $\int \frac{r^2}{2} d\theta$ = the area; then

$$\int \frac{r^2}{2} d\theta = \frac{(r_1^2 + 4r_2^2 + 2r_3^2 + 4r_4^2 + r_5^2)\Delta\theta}{6}$$

30. *To measure any curvilinear area by means of Tchebycheff's rule.*

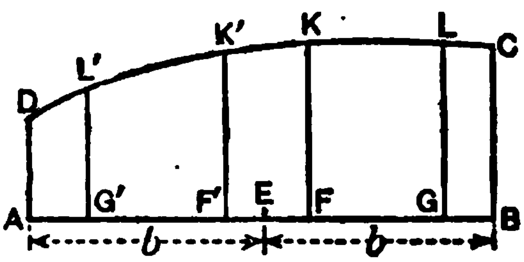
RULE.—Find the middle point of base, and from it set off, along the base, and in both directions, distances equal to the half length of base multiplied by the constants given in the Schedule below. Erect ordinates at the points so obtained and measure them. Their sum, divided by the number of ordinates, and multiplied by the length of base is the area required.

SCHEDULE.	
Number of Ordinates used.	**Distance of Ordinates from Middle of Base in Fractions of Half the Base Length.**
2	·5773
3	O, ·7071
4	·1876, ·7947
5	O, ·3745, ·8325
6	·2666, ·4225, ·8662
7	O, ·3239, ·5297, ·8839
9	O, ·1679, ·5288, ·6010, ·9116

Note.—As evident from the Schedule, there is an ordinate *at* the middle of base, only when an odd number of ordinates is employed.

Examples.—With *four* ordinates. (Fig. 68.)

FIG. 68.

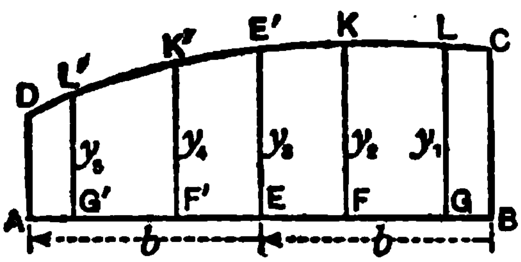


Let ABCD be the figure. Bisect the base AB at E. Calling the half length of base b, set off EF and EF′ equal to ·1876 b and EG and EG′ equal to ·7947 b. Erect ordinates GL, FK, F′K′, G′L′ at G, F, F′, G′; and call them y_1, y_2, y_3, and y_4.

Then area of figure ABCD $= \dfrac{y_1 + y_2 + y_3 + y_4}{4} \times 2b.$

With *five* ordinates. (Fig. 69.)

FIG. 69.



As before, let ABCD be the figure, E the middle of base, and b its half-length. Set off EF and EF′ equal to ·3745 b and EG and EG′ equal to ·8325 b, and erect ordinates at G, F, E, F′, and G′, calling them y_1, y_2, y_3, y_4, y_5.

Then area of figure ABCD $= \dfrac{y_1 + y_2 + y_3 + y_4 + y_5}{5} \times 2b.$

Note.—This rule can be used for calculating displacements, and fewer ordinates are required for the same degree of accuracy than if Simpson's rule is used. Ten ordinates are usually employed instead of twenty-one, the rule for five ordinates being applied separately to each half of the ship. It is also of great assistance in preparing cross curves of stability. If eight ordinates are used (four repeated), the following "Simpson" sections, assumed numbered from 1 to 21, can be utilized: 2, 5, 7, 10, 12, 15, 17, 20.

31. *To measure any curvilinear area by three ordinates irregularly spaced.*

RULE.—Let ABCDEF (Fig. 70) be the curvilinear area, whose ordinates AB, FC, ED, are y_1, y_2, and y_3. Let AF $= h$, and FE $= hk$, where k is a ratio.

$$\frac{h\,(k+1)}{6k}\Big[y_1\,k\,(2-k) + y_2\,(k+1)^2 + y_3\,(2\,k-1)\Big]$$

Note.—If AF $=$ 2FE, so that $k = \frac{1}{2}$,

$$\text{Area} = \frac{\text{AE}}{4}\left(y_1 + 3y_2\right)$$

32. *To find the area between the first two ordinates of a curvilinear area given three ordinates irregularly spaced.*

RULE.—The area included between the ordinates AB and CF.

$$= \frac{k}{6k\,(k+1)}\Big[y_1\,k\,(3k+2) + y_2\,(3k+1)\,(k+1) - y_3\Big]$$

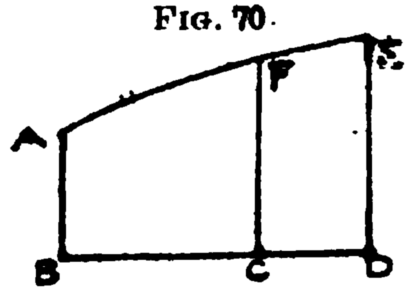
Note.—If AF $=$ 2FE, so that $k = \frac{1}{2}$,

$$\text{Area} = \frac{\text{AF}}{18}\left(7\,y_1 + 15y_2 - 4y_3\right)$$

If AF $= \frac{1}{2}$FE, so that $k = 2$,

$$\text{Area} = \frac{\text{AF}}{36}\left(16y_1 + 21y_2 - y_3\right)$$

FIG. 70.



33. *To obtain a general expression for the length of any plane curve.*

Using cartesian co-ordinates the length intercepted between two points whose 'x' co-ordinates are a and b is equal to the definite integral $\int_a^b \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\,.\,dx$. This may be obtained by Simpson's rules in a similar way to the area; the 'ordinate' in this case being replaced by the value of $\sqrt{1 + \left(\frac{dy}{dx}\right)^2}$ or sec. ϕ, and the common interval being measured along Ox.

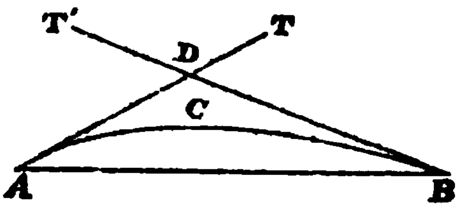
34. *To find approximately the length of any plane curve.* (Fig. 71.)

If the curve is rather irregular, divide it by the eye into any number of fairly flat arcs; join the extremities of each of these arcs by chords. The sum of the length of each of these arcs found by the following rule will be the total length of the curved line.

RULE.—Draw a tangent to the curve at each of its extremities; then take the sum of the two distances from the point of intersection of the two tangents to the extremities of the curve, together with twice the length of the chord; divide the result by 3 for the length of the arc.

Ex. (fig. 71): Let ACB be one of the arcs, and AB a chord joining the two extremities, and AT, BT′ tangents to the curve at its extremities, cutting each other in D; then the length of the curve

FIG. 71.



$$ACB = \tfrac{1}{3}(AD + DB + 2AB).$$

Alternatively, for a flat curve see Rule III, p. 38.

35. *To find the perimeter of an ellipse of moderate eccentricity.*

RULE.—If $2a$ is the major and $2b$ the minor axis, where $\frac{b}{a}$ is not very small, then the perimeter is equal to $\frac{\pi}{2a}(3a^2 + b^2)$ very nearly.

36. *To find the length of the evolute of a curve.*

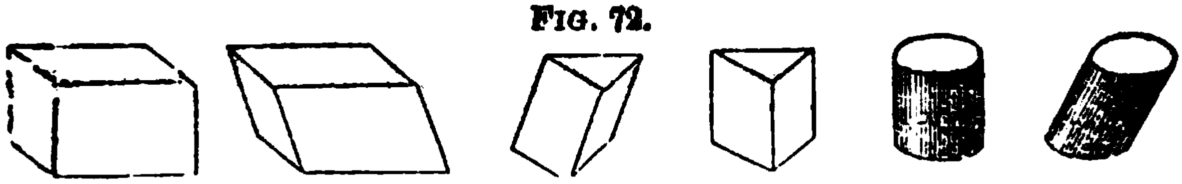
RULE.—The length of the arc of the evolute is equal to the difference between the lengths of the tangents drawn from either extremity of the arc to the involute.

II. MENSURATION OF SOLIDS.

1. *To find the volume of any parallelopiped, prism, or cylinder.* (Fig. 72.)

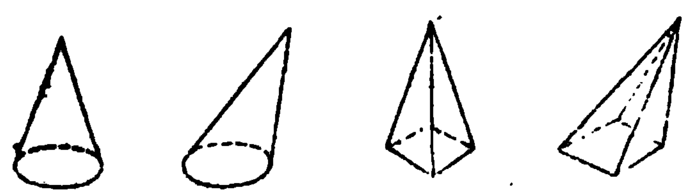
RULE.—Multiply the area of the base by the perpendicular height; the result will be the volume.

FIG. 72.



2. *To find the volume and slant surface of a cone or pyramid.* (Fig. 73.)

FIG. 73.



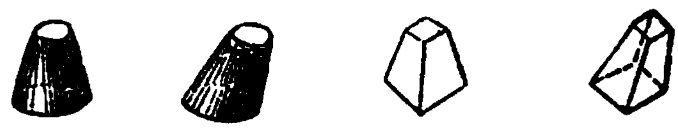
RULE.—Multiply the area of the base by $\frac{1}{3}$ the perpendicular height; the product will be the volume. The slant

surface is equal to the perimeter of the base multiplied by half the slant height.

3. *To find the volume and slant surface of the frustum of a cone or pyramid.* (Fig. 74.)

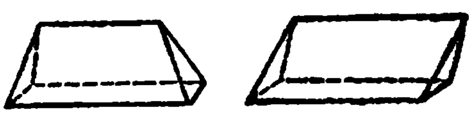
RULE.—To the sum of the areas of the two ends add the square root of their product; this final sum being multiplied by $\frac{1}{3}$ of the perpendicular height will give the volume. The slant surface is the product of the sum of the perimeter of the two ends and half the slant height.

FIG. 74.



4. *To find the volume of a wedge whose base is a parallelogram.* (Fig. 75.)

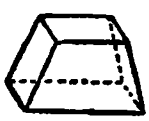
FIG. 75.



RULE.—Add the length of the edge to twice the length of the base; multiply the sum by the width of the base and the product by $\frac{1}{6}$ of the perpendicular height: the result will be the volume.

5. *To find the volume of a prismoid.* (Fig. 76.)

FIG. 76.



RULE.—To the sum of the areas of the two ends add four times the area of a section parallel to the base and equally distant from both ends; the sum being multiplied by $\frac{1}{6}$ the perpendicular height will give the volume.

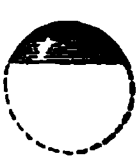
6. *To find the volume and surface of a sphere or globe.* (Fig. 77.)

FIG. 77.

RULE.—Multiply the cube of the diameter by $\frac{\pi}{6}$ or ·5236; the product will be the volume. To obtain the surface, multiply the square of the diameter by π or 3·1416.

7. *To find the volume and surface of the segment of a sphere.* (Fig. 78.)

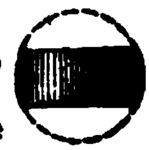
FIG. 78.



RULE.—Add the square of the height to 3 times the square of the radius of the base; that sum multiplied by the height and that product by $\frac{\pi}{6}$ or ·5236 will give the volume. To obtain the surface, multiply the diameter of the whole sphere by the height of the segment and that product by π or 3·1416.

8. *To find the volume and surface of a zone of a sphere.* (Fig. 79.)

FIG. 79.



RULE.—To the sum of the squares of the radii of the two ends add $\frac{1}{3}$ the square of the height; multiply the sum by the height and that result by $\frac{\pi}{2}$ or 1·5708: the result will be the volume. To obtain the surface, multiply the diameter of the whole sphere by the height of the zone, and that product by π or 3·1416.

9. *To find the volume and surface of a cylindrical ring.*

RULE.—To the thickness of the ring add the inner diameter; multiply that sum by the square of the thickness, and the product by $\frac{\pi^2}{4}$ or 2·4674: the result will be the volume. To obtain the surface, multiply the sum of the inner diameter and thickness by the thickness, and that product by π^2 or 9·87.

TABLE TO FIND THE VOLUME AND SURFACE OF ANY REGULAR POLYHEDRON.

V = volume. A = area. L = linear edge.
r = radius of inscribed circle.

No. of Sides	No. of Edges in each side	Name	$A = L^2 \times$	$V = L^3 \times$	$r = L \times$
4	3	Tetrahedron	1·732051	·117851	·204124
6	4	Hexahedron[1]	6·000000	1·000000	·500000
8	3	Octahedron	3·464102	·471405	·408248
12	5	Dodecahedron	20·645729	7·663119	1·113516
20	3	Icosahedron	8·660254	2·181695	·755750

[1] Or cube.

10. *To find the volume of an ellipsoid.* (Fig. 80.)

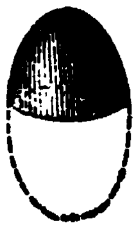
FIG. 80.

RULE.—Multiply the product of the three principal axes by $\frac{\pi}{6}$ or ·5236: the result will be the volume.

11. *To find the volume of the segment of an ellipsoid of revolution when the base is circular.* (Fig. 81.)

RULE.—Take double the height of the segment from

FIG. 81.

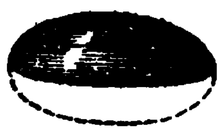


three times the length of the fixed axis; multiply the difference by the square of the height, and that product by $\frac{\pi}{6}$ or ·5236: then that result multiplied by the square of the revolving axis and the product divided by the square of the fixed axis will give the volume.

12. *To find the volume of the segment of an ellipsoid of revolution when the base is elliptical.* (Fig. 82.)

RULE.—Take double the height of the segment from three times the length of the revolving axis; multiply the difference by the square of the height, and that product by $\frac{\pi}{6}$ or ·5236: then that result multiplied by the fixed axis, and the product divided by the revolving axis, will give the volume.

FIG. 82.



13. *To find the volume of the middle frustum of an ellipsoid of revolution when the ends are circular.* (Fig. 83.)

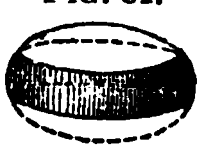
FIG. 83.

RULE.—Multiply the sum of the square of the middle diameter and one-half the square of the diameter of one end by the length of the frustum, and that product by $\frac{\pi}{6}$ or ·5236 for the volume.

14. *To find the volume of the middle frustum of an ellipsoid of revolution when the ends are elliptical.* (Fig. 84.)

RULE.—To twice the product of the transverse and conjugate diameters of the middle section, add the product of the transverse and conjugate diameters of one end; multiply the sum by the height of the frustum, and that product by $\frac{\pi}{12}$ or ·2618: the result will be the volume.

FIG. 84.



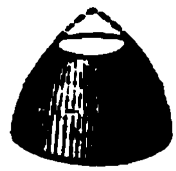
15. *To find the volume of a paraboloid.* (Fig. 85.)

FIG. 85.

RULE.—Multiply the square of the diameter of the base by the perpendicular height, and the result by $\frac{\pi}{8}$ or ·3927; the product will be the volume.

16. *To find the volume of the frustum of a paraboloid when its ends are perpendicular to its axis.* (Fig. 86.)

FIG. 86.



RULE.—Multiply the sum of the squares of the diameters of the two ends by the height of the frustum; the product multiplied by $\frac{\pi}{8}$ or ·3927 will be the volume.

17. *To find the volume of any solid of revolution.*

(I) The volume is represented by the definite integral $\int_0^h \pi y^2 . dx$, where Ox is the axis of symmetry.

RULE.—Divide the length of the axis into a convenient number of equal parts. Measure the ordinates, and treat their squares as if they were the ordinates of a plane curve of the same length as the solid; the area of this curve multiplied by π or 3·1416 will be the volume required.

(II) If the position of the centre of gravity of the generating area is known, the following method is applicable.

RULE.—Multiply the area of the generating section by the distance of its centre of gravity from the axis; 2π or 6·283 times the product will be the volume required.

Example.—Find the volume of the solid generated by the revolution of an equilateral triangle about its base.

If $2a$ be the side of the triangle, its area is $\sqrt{3} . a^2$; and its centre of gravity is $\frac{a}{\sqrt{3}}$ from the base. Hence the volume required is $2\pi \times \sqrt{3}a^2 \times \frac{a}{\sqrt{3}} = 2\pi a^3$.

18. *To measure the volume of any solid.*

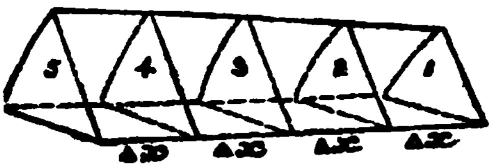
(I) *To measure the volume in slices.*

RULE.—Take one of the plane surfaces as the base, and divide the mass into slices parallel to that base and sufficiently thin as to be able either to neglect or account separately for the curvature.

Then take the volume of each slice separately, and add them together for the whole volume, taking account of the curvature in this addition if necessary.

(II) *To measure the volume by the rules applicable to the area of a plane curve.* (Fig. 87.)

FIG. 87.



RULE.—Take a straight line in the figure as a base line, or line of abscissa, and divide the figure along that line into any number of equal parts, and measure the areas of the plane sections at those points of division by the rules applicable to the area of a plane curve.

Then treat the areas thus found as if they were the ordinates of a plane curve of the same length as the figure, and the area of this will be the volume of the solid.

Example. (See fig. 87.)

Number of Sections	Areas of Sections in square feet	Multipliers	Products
1	5	1	5
2	10	4	40
3	15	2	30
4	20	4	80
5	25	1	25
			180
		$\frac{\Delta x}{3} =$	2

Area = 360 cubic feet.

Remark.—The volume is above assumed to be represented by the definite integral $\int_0^h$ A . dx, where A is the area of any section perpendicular to the base line ox. The volume may also be represented by the double integral $\iint z \, . \, dx \, . \, dy$ taken over the area of the base, the z axis being supposed perpendicular to the base.

(III) *To measure the volume by Dr. Woolley's method.* (Fig. 88.)

RULE.—Take a straight line in the figure as a base line, and divide the figure along that line by an odd number of parallel and equidistant planes perpendicular to the base. Then divide the figure horizontally in the same way by a number of plane sections parallel to the base. Then take ordinates at the intersections of the horizontal with the vertical plane sections in their consecutive order, and treat them as follows :—

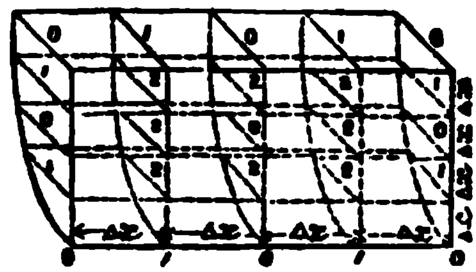
(1) Neglect absolutely all ordinates which are *odd* in *both* planes of section.

(2) Neglecting the outside rows of ordinates, double every ordinate which is *even* in *either* or *both* planes of section, and add them together.

(3) Add to this the simple sum of all the *even* ordinates in the outside rows.

(4) Multiply this final sum by $\frac{2}{3}$ of the product of the common vertical interval, by the common horizontal interval, and the result will be the volume.

FIG. 88.



Ex.: In the accompanying figure the multiplier for each ordinate is shown above it, so that if s = the sum of the products of the ordinates by their respective multipliers, V = the volume, and $\Delta x'$ = the common vertical interval, and Δx = the common horizontal interval, then

$$V = \frac{2(s \times \Delta x' \times \Delta x)}{3}$$

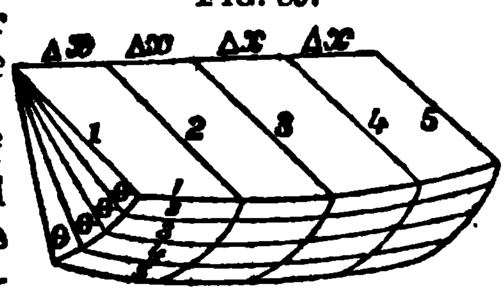
Remark.—This method is inferior in accuracy to that obtained by a double application of Simpson's rules.

19. *To measure the volume of a wedge-shaped solid bounded on one side by a curved surface.* (Fig. 89.)

The volume is represented by the double integral $\iint \frac{1}{2} r^2 . dx . d\theta$, where r is a radius from the edge. θ is the angle between the radius and the plane of the base, and Ox is parallel to the edge.

RULE.—Divide the figure longitudinally by a number of planes radiating from the edge at equal angular intervals, and also divide the length of figure into a number of equal intervals for ordinates, and treat each of the radiating planes as follows:—

FIG. 89.



(I) Measure the ordinates as if for taking the areas of the several planes, but instead of the ordinates themselves compute their half-squares, and treat them as if they were the ordinates of a plane curve of the same length as the figure. The result of this calculation is called the moment of the radiating plane.

(II) Treat the moments of the radiating planes as if they were the ordinates of a curve, but taking the common angular interval in circular measure.

Example. (See fig. 89.)

No. of Planes	Moments of the Radiating Planes	Multipliers	Products
1	105	1	105
2	110	4	440
3	115	2	230
4	120	4	480
5	125	1	125

$$\begin{array}{r} 1380 \\ \frac{\theta}{3} = \frac{\text{angular interval}}{3} = \underline{\cdot 0291} \\ 1380 \\ 12420 \\ \underline{2760} \\ \text{Volume} = \underline{40 \cdot 1580} \end{array}$$

20. *To find the mean sectional area of a solid.*

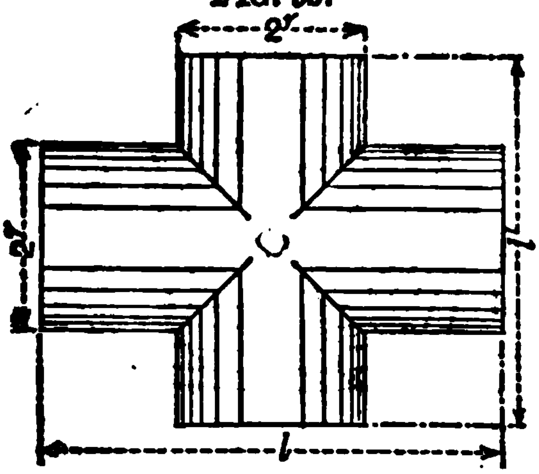
RULE.—Divide the volume of the solid by its length; the result will be the mean sectional area.

21. *To set off the correct form of a mean cross-section.*

RULE.—Divide the figure longitudinally by a number of horizontal planes; take the mean breadth of each of the horizontal planes and set them off perpendicular to a fixed straight line, and at the same height as their corresponding planes in the solid: a line passing through the ends of these mean breadths will be the correct form of the mean sectional area of the solid.

Note.—The mean breadth of a plane curve is found by dividing the area of the curve by its length.

FIG. 90.



22. *To find the volume of a fourway piece of piping.*

Let r (fig. 90) be the radius of the piping and l and l' the lengths.

Then volume $= \pi r^2 (l + l' - \frac{2}{3}r)$.

23. *To find the surface of any solid of revolution.*

(I) The surface is represented by the definite integral $\int_0^h \pi y \,.\, ds$, where ds is an element of arc of the generating curve.

RULE.—Divide the perimeter of the generating curve into a convenient number of equal arcs. Measure the ordinates at the points of division, and treat them as if they were the equidistant ordinates of a curve, with the common interval equal to the length of the arcs. The area of this curve multiplied by 2π or 6·283 will be the area of the surface.

(II) If the position of the centre of gravity of the periphery of the generating curve is known, the following method is applicable :—

RULE.—Multiply the length of the arc of the generating curve by the distance of the centre of gravity *of the arc* from the axis ; 2π or 6·283 times the product will be the area of the surface.

Example.—Find the surface of the solid generated by the revolution of an equilateral triangle about its base.

If $2a$ be the side of the triangle, its perimeter, exclusive of the axis, is $4a$; and the centre of gravity of the two sides is $\sqrt{3}a/2$ from the base.

Hence the surface required is $2\pi \times 4a \times \sqrt{3}\,a/2 = 4\sqrt{3}\,\pi a^2$.

24. *To find the area of any surface.*

(I) *Exact method.*—The area is given by the double integral $\iint \sec\theta \,.\, dx \,.\, dy$, where θ is the angle made by the surface with the xy plane. This is equal to $\iint \sqrt{(1 + \tan^2\phi + \tan^2\psi)}\,.$ $dx \,.\, dy$, where ϕ and ψ are the angles made with the z axis by the sections of the surface with the xz and yz planes.

RULE.—Take a straight line in the figure as base line and divide the figure along that line by a convenient number of parallel and equidistant planes perpendicular to the base ; call these the vertical sections. Then divide the figure horizontally in the same way by a number of plane sections parallel to the base. At the intersections of the two sets of sections measure $\tan\phi$ and $\tan\psi$, ϕ and ψ being the angles made in the sections by the tangents to the curves with the base. Evaluate $\sqrt{1 + \tan^2\phi + \tan^2\psi}$ at each intersection. Treat this as the ordinate of a solid, and proceed to find its volume by any of the rules given above. The result is the area required. It is desirable that no part of the surface should be approximately perpendicular to the base.

Example.—A portion of a ship's side is bounded by two sections 40 feet apart, and two waterlines 8 feet apart. The tangents of the angles (ϕ) made with the middle line at the sections and at one situated midway between them, and the

tangents of the angles (ψ) made with the middle line at the two waterlines, and at one midway, are as follows:—

W.L.	Section 1		Section 2		Section 3	
	$\tan\phi$	$\tan\psi$	$\tan\phi$	$\tan\psi$	$\tan\phi$	$\tan\psi$
1	·30	·21	·35	·16	·48	·06
2	·21	·22	·31	·17	·44	·07
3	·10	·22	·14	·18	·25	·09

Find $\sqrt{1 + \tan^2\phi + \tan^2\psi}$ in each case, and proceed as in the table below:—

W.L.	Simpson's Multiplier	Section 1 $\sqrt{1+\tan^2\phi+\tan^2\psi}$	Product	Section 2 $\sqrt{1+\tan^2\phi+\tan^2\psi}$	Product	Section 3 $\sqrt{1+\tan^2\phi+\tan^2\psi}$	Product
1	1	1·06	1·06	1·07	1·07	1·11	1·11
2	4	1·04	4·16	1·06	4·24	1·10	4·40
3	1	1·03	1·03	1·03	1·03	1·02	1·02
			7·25		6·34		6·53
			1		4		1
			7·25	+	25·36	+	6·53
							= 39·14

The area of the curved surface is $39{\cdot}14 \times \frac{20}{3} \times \frac{4}{3} = 348$ square feet.

(II) *Approximate method.*

RULE.—Take girths along (say) the vertical sections at equidistant intervals. For each section in the half-breadth plan, note the angle at which the various waterlines cross, and estimate the mean slope of the waterlines surrounding the surface under question. The secant of this mean angle with the middle line is termed the modifying factor, and is multiplied by the girth concerned. These modified girths are then regarded as the ordinates of a curve, whose area is the surface required.

Example.—In the previous example, the girths at Sections 1, 2, and 3 are 8·2, 8·3, and 8·7 feet respectively. The respective mean angles of the waterlines with the middle line are ·22, ·17, and ·07. Find the surface.

The first modifying factor is $\sqrt{1 + (\cdot 22)^2}$ or 1·02; similarly the others are 1·015 and 1·0 approximately.

No.	Girth	Modifying Factor	Modified Girth	Simpson's Multiplier	Product
1	8·2	1·02	8·4	1	8·4
2	8·3	1·015	8·45	4	33·8
3	8·7	1·0	8·7	1	8·7
					50·9

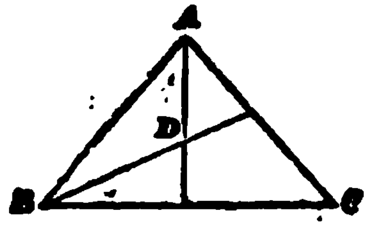
Area of surface $= 50{\cdot}9 \times \frac{20}{3} = 340$ square feet approximately.

CENTRES AND MOMENTS OF FIGURES.

To find the Centres of Gravity of a few Special Figures.

1. *Triangle.* (Fig. 91.)

Fig. 91.

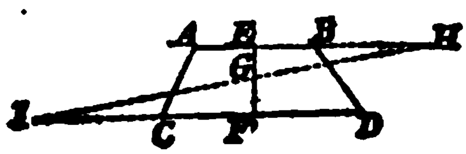


Rule.—From the middle points of any two sides draw lines to the opposite angle; the point of intersection D of these lines is the required centre.

Or, trisect the line joining the middle point of one side with the opposite vertex; the point of trisection nearer to the base is the required centre.

2. *Trapezoid.* (Fig. 92.)

Fig. 92.

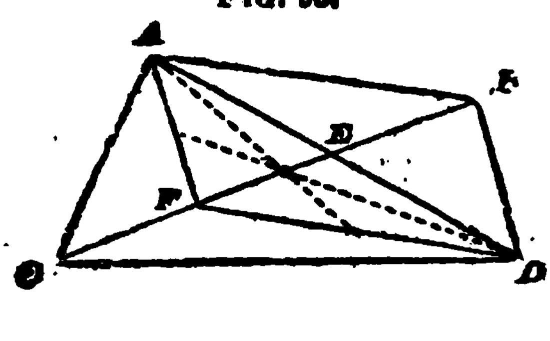


Rule.—Bisect AB in E and CD in F and join EF. Produce AB beyond B to H, making BH = CD, and produce CD beyond C to I, making CI = AB; then join HI, and where this line intersects EF is the centre of gravity G.

Note.—EG is to GF as 2CD + AB is to 2AB + CD. If the angles at A and C are right angles, the distance of G from AC is equal to $\frac{AB^2 + AB \cdot CD + CD^2}{3\,(AB + CD)}$

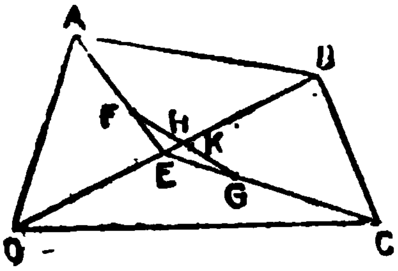
3. *Quadrilateral.* (Fig. 93.)

Fig. 93.



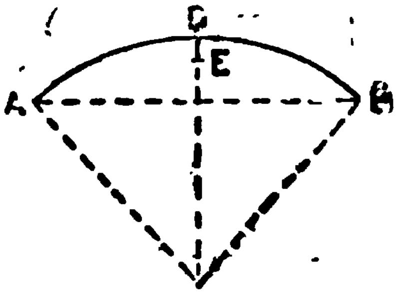
Rule.—Draw the diagonals AD and CB intersecting in E; along CB set off CF equal to EB, and join FA and FD; the centre of the triangle AFD will be the centre of the quadrilateral.

FIG. 93A.



Or, bisect the diagonal BD (fig. 93A) at E; join EA, EC. Make EF $= \frac{1}{3}$EA and EG $= \frac{1}{3}$EC. Join FG, cutting BD at H. Make KG = HF. Then K is the required centre.

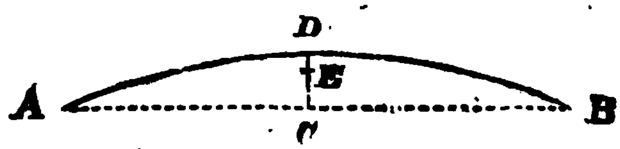
FIG. 94.



4. *Circular arc.* (Fig. 94.)

RULE.—Let ADB be the circular arc and C the centre of the circle of which it is a part: bisect the arc AB in D, and join DC and AB; multiply the radius CD by the chord AB, and divide by the length of the arc ADB; lay off the quotient CE upon CD; then E is the centre required.

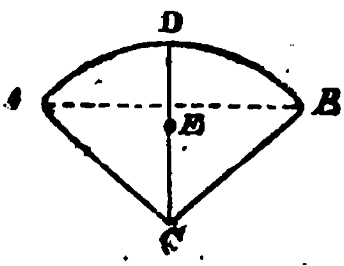
FIG. 95.



5. *Very flat curved line (approximate).* (Fig. 95.)

RULE.—Let ADB be the arc; draw the chord AB, and bisect it in C; draw CD perpendicular to AB; make CE equal to $\frac{2}{3}$ of CD; then E will be the centre required.

FIG. 96.

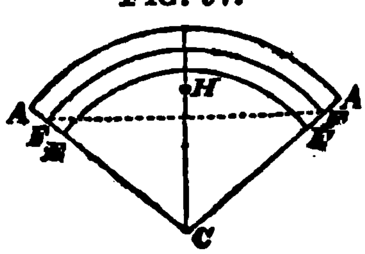


6. *Sector of a circle.* (Fig. 96.)

RULE.—Let ABC be the sector, E its centre; multiply the chord AB by $\frac{2}{3}$ of the radius CA; divide the product by the length of the arc: the quotient equals the distance CE set along the line CD, D being at the bisection of the arc AB.

7. *Sector of a plane circular ring.* (Fig. 97.)

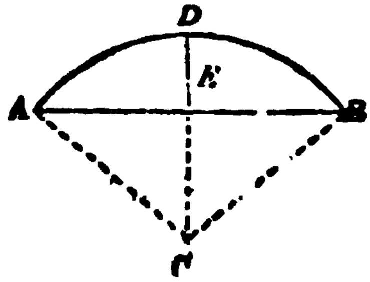
FIG. 97.



RULE.—Let CA be the outer and CE the inner radius of the ring; divide twice the difference of the cubes of the inner and outer radii by three times the difference of their squares; the quotient will be an intermediate radius CF, with which describe the arc FF, subtending the same angle with the sector: the centre H of the circular arc FF, found by Rule 4, will be the centre required.

8. *Circular segment.* (Fig. 98.)

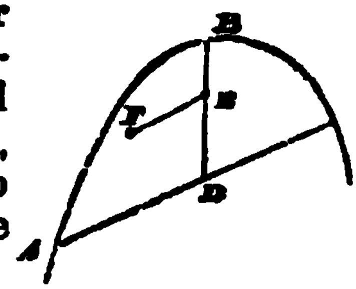
FIG. 98.



RULE.—Let C be the centre of the circle of which it is a part; bisect the arc AB in D, and join CD; divide the cube of half the chord AB by three times the area of half the segment ADB; set off the quotient CE along CD, and E will be the centre required.

9. *Parabolic half-segment.* (Fig. 99.)

FIG. 99.



RULE.—Let ABD be a half-segment of a parabola, BD being part of a diameter parallel to the axis and AD an ordinate conjugate to that diameter—that is, parallel to a tangent at B. Make BE equal to $\frac{2}{5}$ BD, and draw EF parallel to AD and equal to $\frac{3}{8}$ AD. Then F will be the centre of the half-segment.

10. *Height of centre of semicircle or semi-ellipse from its base.*

RULE.—Multiply the radius of the semicircle (or that semi-axis of the ellipse which is perpendicular to the base) by 4, and divide the product by 3π.

11. *Height of centre of parabola from its base.*

RULE.—Multiply its vertical height by 2, and divide the product by 5.

12. *Prism or cylinder with plane parallel ends.*

RULE.—Find the centres of the ends; a straight line joining them will be the axis of the prism or cylinder, and the middle point of that line will be the centre required.

13. *Cone or pyramid.*

RULE.—Find the centre of the base, from which draw a line to the summit; this will be the axis of the cone or pyramid, and the point at $\frac{1}{4}$ from the base along that line will be the centre.

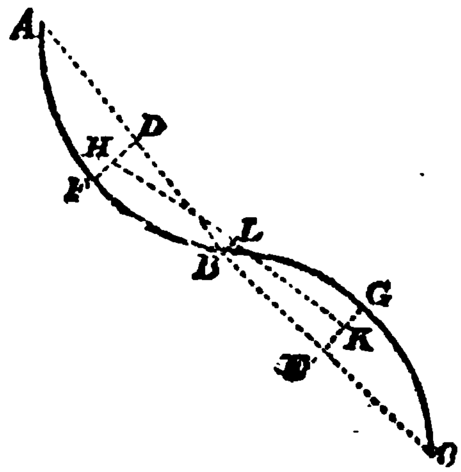
14. *Hemisphere or hemi-ellipsoid.*

RULE.—The distance of the centre from the circular or elliptic base is $\frac{3}{8}$ of the radius of the sphere, or of that semi-axis of the ellipsoid which is perpendicular to the base.

15. *Paraboloid.*

RULE.—The distance of its centre from the base along its axis is $\frac{1}{3}$ of the height from the base.

FIG. 100.



16. *To find the centre of gravity of any continuous curved line.* (Fig. 100.)

Ex.: Let ABC be the given curve; bisect it at B; join AB and BC, and bisect those chords at the points D and E respectively; set off FD perpendicular to AB, and EG perpendicular to BC; make FH $= \frac{1}{3}$DF and GK $= \frac{1}{3}$GE, and join HK; bisect HK at the point L, which will be a close approximation to the position of the centre of gravity of the curved line ABC.

Remark.—If the line is too irregular to permit its two parts to be regarded as flat regular curves, it should be divided into four or eight parts as required. The points corresponding to L in the above figure are found separately for each pair of parts, joined in pairs and bisected; this process is repeated until only one point remains, this being the required centre of gravity.

RULES FOR FINDING THE MOMENTS AND CENTRES OF FIGURES.

The geometrical moment of a figure, whether a line, an area, or a solid, relatively to a given plane or axis is the product of the magnitude of that figure, into the perpendicular distance of its centre from the given plane or axis, and is equal to the sum of the moments of all its parts relatively to the same plane.

The centre of an area is determined when its distance from two axes in the plane of the figure is known.

The centre of a figure of three dimensions is determined

when its distance from three planes not parallel to one another is known.

1. *To find the moment of an irregular figure relatively to a given plane or axis.*

RULE.—Divide the figure into parts whose centres are known; multiply the magnitude of each of its parts into the perpendicular distance of its centre from the given plane or axis; distinguish the moments into positive and negative, according as the centres of the parts lie to one side or the other of the plane: the difference of the two sums will be the resultant moment of the figure relatively to the given plane or axis, and is to be regarded as positive or negative, according as the sum of the positive or negative moments is the greater.

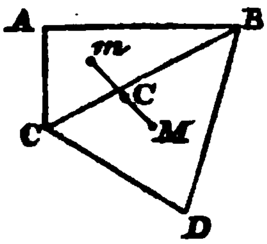
2. *To find the perpendicular distance of the centre of an irregular figure from a given plane or axis.*

RULE.—Divide the moment of that figure relatively to the given plane or axis by its magnitude; the quotient will be the perpendicular distance of its centre from the given plane or axis.

3. *To find the centre of a figure consisting of two parts whose centres are known.* (Fig. 101.)

RULE.—Multiply the distance between the two known centres by the magnitude of either of the parts, and divide the product by the magnitude of the whole figure; the quotient will be the distance of the centre of the whole figure from the centre of the other part, the centre of the whole figure being in the straight line joining the centres of the two parts.

FIG. 101.

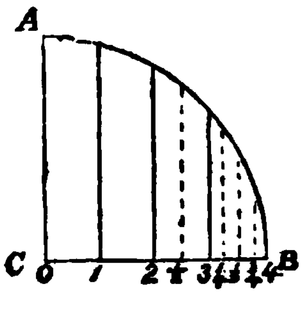


Ex.: Let ABCD be such a figure, M and m the magnitude of its two respective parts, $M + m$ the magnitude of the whole figure, D the distance between the centres M and m of the two parts, and C the centre of the whole figure.

$$MC = \frac{m \times D}{M + m} \qquad mC = \frac{M \times D}{M + m}.$$

4. *To find the centre of any plane area by means of ordinates.* (Fig. 102.)

FIG. 102.



Let ABC, the quadrant of a circle, be such an area; CB the base line, divided into a number of equal parts by ordinates; AC the transverse axis traversing its origin.

1*st*. *Determine the perpendicular distance of the centre of the quadrant from the transverse axis in the following manner:—*

RULE.—Multiply each ordinate by its distance from the transverse axis; consider the products as ordinates of a new curve of the same length as the given figure: the area of that curve, found by the proper rule, will be the moment of the figure relatively to the transverse

axis; this moment, divided by the whole area of the figure, will give the perpendicular distance of its centre from the transverse axis.

In algebraical symbols the moment of a plane figure relatively to its transverse axis, and found by the above rule, is expressed thus:—

$$\int xy\,dx.$$

Note.—In practice it is better to proceed as follows:—Multiply the ordinates first by their multipliers, and then those products by the number of intervals from the origin; take the sum of those products and multiply it by $\frac{1}{3}$rd of a whole interval squared, if Simpson's first rule is used, by $\frac{3}{8}$ths of a whole interval squared, if Simpson's second rule is used, and so on for the other rules.

Example.

No. of Intervals	Ordinates	Multipliers	Products	Products × No. of Intervals from Origin
0	16·0000	1	16·0000	·00000
1	15·4919	4	61·9676	61·9676
2	13·8564	$1\frac{1}{2}$	20·7846	41·5692
$2\frac{1}{2}$	12·4900	2	24·9800	62·4500
3	10·5830	$\frac{3}{4}$	7·93725	23·81175
$3\frac{1}{4}$	9·3274	1	9·3274	30·31405
$3\frac{1}{2}$	7·7460	$\frac{1}{2}$	3·8730	13·5555
$3\frac{3}{4}$	5·5678	1	5·5678	20·87925
4	0·0000	$\frac{1}{4}$	0·0000	·00000
		$\frac{\text{Interval}}{3} =$	150·43765	254·54735
			$\frac{4}{3}$	$\frac{\text{Interval}^2}{3} = \frac{16}{3}$
		Approximate area =	200·58353	Approx. moment = 1357·585

$$\frac{\text{Moment } 1357\cdot585}{\text{Area } 200\cdot5835} = 6\cdot768 \begin{cases}\text{approximate perpendicular distance}\\ \text{of centre from the transverse axis.}\end{cases}$$

2nd. Find the perpendicular distance of its centre from the base line.

RULE.—Square each ordinate, and take the half-squares as ordinates for a new curve of the same length as the figure; the area of that curve, found by the proper rule, will be the moment of the figure relatively to the base line: this moment, divided by the whole area of the figure, will give the perpendicular distance of its centre from the base line.

In algebraical symbols the moment of a plane figure relatively to its base line, found by the above rule, is expressed thus:—

$$\int \frac{y^2}{2}\,dx.$$

Example.

No. of Intervals	Ordinates	Half-squares	Multipliers	Products
0	16·0000	128·0000	1	128·0000
1	15·4919	119·9995	4	479·9980
2	13·8564	95·9999	2	191·9998
3	10·5830	55·9999	4	223·9996
4	0·0000	0·0000	1	0·0000
				1023·9974
			$\frac{\text{Interval}}{3} =$	$\frac{4}{3}$
			Approximate moment =	1365·3298

$$\frac{\text{Moment } 1365{\cdot}3298}{\text{Area } 201{\cdot}0624} = 6{\cdot}796 \begin{cases} \text{approximate perpendicular dis-} \\ \text{tance of centre from base.} \end{cases}$$

$$\frac{\text{Actual moment} = 1365{\cdot}3}{\text{Actual area} \quad = 201{\cdot}0624}$$

5. *To find the centre of a plane area bounded by a curve and two radii by means of polar co-ordinates.* (See fig. 68.)

1st. *Determine the perpendicular distance of its centre from a plane traversing the pole and at right angles to one of the bounding radii, called the first radius, in the following manner:—*

Rule.—Divide the angle subtended by the arc into a convenient number of equiangular intervals by means of radii; measure the lengths of the radii from the pole to the arc, and multiply the third part of the cube of each of them by the cosine of the angle which they respectively make with the first radius; treat these products by one of the rules applicable to finding the area of a plane curve (the only difference being that the common interval is taken in circular measure); the result will be the moment of the figure relatively to the plane traversing the pole: this moment, divided by the area of the figure, will give the perpendicular distance of its centre from the plane traversing the pole.

Example.

No. of Radii	Radii	Cubes of Radii / 3	Angles with First Radius	Cosines	Products	Simpson's Multipliers	Products
1	12	576	0°	1·0000	576·0000	1	576·0000
2	12	576	5°	·9962	573·8112	4	2295·2448
3	12	576	10°	·9848	567·2448	2	1134·4896
4	12	576	15°	·9659	556·3584	4	2225·4336
5	12	576	20°	·9397	541·2672	1	541·2672
							6772·4352
						$\frac{\text{Interval in circular measure}}{3} =$	·0291
						Moment relatively to plane traversing pole =	197·077864

$$\frac{\text{Moment } 197\cdot077864}{\text{Area } 25\cdot1327} = 7\cdot841 \left\{\begin{array}{l}\text{perpendicular distance of centre}\\ \text{from plane traversing pole.}\end{array}\right.$$

In algebraical symbols the moment, as here found, is expressed thus:—

$$\int \frac{r^3}{3} \cos \theta d\theta.$$

2nd. *Determine the moment of the figure relatively to the first radius precisely in the same way as in the foregoing rule, with the exception that sines must be used in the place of cosines; this moment, divided by the area of the figure, will give the perpendicular distance of its centre from the first radius.*

Note.—It is usual, in practice, to defer the division of the cubes of the radii by 3 until after the addition of the products.

Example.

No. of Radii	Radii	Cubes of Radii / 3	Angles with First Radius	Sines of Angles	Products	Simpson's Multipliers	Products
1	12	576	0°	·0000	·0000	1	·0000
2	12	576	5°	·0872	50·2272	4	200·9088
3	12	576	10°	·1736	99·9936	2	199·9972
4	12	576	15°	·2588	149·0688	4	596·2752
5	12	576	20°	·3420	196·9920	1	196·9920
							1194·1732
					Interval in circular measure / 3 =		·0291
					Moment relatively to first radius =		34·750440

$$\frac{\text{Moment } 34\cdot75044}{\text{Area } 25\cdot1327} = 1\cdot38 \left\{\begin{array}{l}\text{perpendicular distance of centre from}\\ \text{first radius.}\end{array}\right.$$

In algebraical symbols the moment as here found is expressed thus:—

$$\int \frac{r^3}{3} \sin \theta d\theta.$$

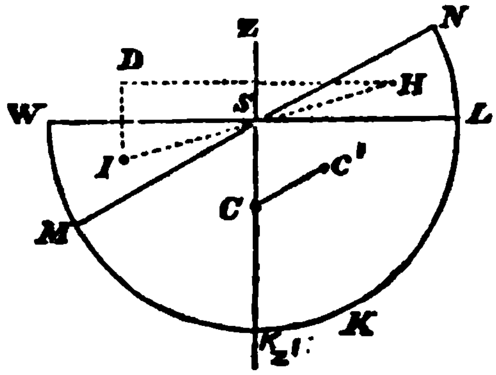
6. *To find the perpendicular distance of the centre of a solid, bounded on one side by a curved surface* (figs. 87 and 88), *from a plane perpendicular to a given axis at a given point.*

RULE.—Proceed as in Rule 4, p. 63, to find the moment relatively to the plane, substituting sectional areas for breadths: then divide the moment by the volume (as found by Rule 2, p. 54); the quotient will be the required distance. To determine the centre completely, find its distance from three planes no two of which are parallel.

7. *Having the moment and centre of a figure relatively to a given plane, to find the new moment and centre of the figure relatively to the same plane when a part of the figure is shifted.* (Fig. 103.)

In the figure WLK let C be its centre, and ZZ′ a plane with respect to which the moment of the figure is known; suppose the part WSM to be transferred to the new position SNL, so as to alter the shape of the figure from WLK to MNK; let I be the original and H the new centre of the shifted part: then *the moment of the figure MNK relatively to the plane ZZ′ is found as follows:—*

FIG. 103.



RULE.—Measure the distance, perpendicular to the plane of moments, between the centres of the original and new position of the shifted part, as HD, and multiply it by the magnitude of the shifted part; the product will be the moment required. *The new position of the entire figure is then found by the following rule:—*

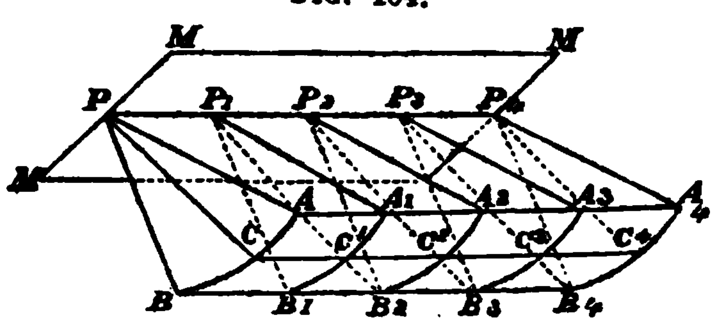
RULE.—Multiply the distance between the centres of the original and new position of the shifted part by the magnitude of that part; that product, divided by the magnitude of the whole figure, will give the distance the centre has traversed in the direction in which the part has been shifted, and in a plane parallel to a line joining the centres of the original and new position of the shifted part, as from C to C′ in fig. 103.

8. *To find the centre of a wedge-shaped solid* (fig. 104) *by means of polar co-ordinates.*

1st. *Determine the perpendicular distance of its centre relatively to a transverse sectional plane, as* PAB.

RULE.—Divide the solid by a number of parallel and equidistant planes, as PAB, $P_1A_1B_1$, $P_2A_2B_2$, &c.; then multiply each sectional area by its distance from the plane PAB; treat the products as though they were the ordinates of a curve of the same length as the figure; the area of that curve, found by the proper rule, will be the moment of the figure relatively to the plane PAB: that moment, divided by the volume of the figure, will be the distance required.

FIG. 104.



2nd. Determine the perpendicular distance of its centre relatively to a longitudinal plane passing through its edge, as MPM, *perpendicular to the first radius,* PB.

RULE.—Divide the figure by a number of longitudinal planes radiating from the edge MPM at equiangular intervals (as PP_4AA_4, PP_4CC_4, PP_4BB_4); also divide the length of the figure into a number of equal intervals by ordinates, and treat each of the longitudinal planes as follows:—Measure its ordinates, take the third part of their cubes, and treat those quantities as if they were ordinates of a new curve; that is, find its area by one of Simpson's rules: the area of that new curve is termed the moment of inertia of the longitudinal plane in question. Then multiply each moment of inertia of the several planes by the cosine of the angle made by the plane to which it belongs with the plane PB, and treat these products by a proper set of Simpson's multipliers; add together the products, and multiply the sum by $\frac{1}{3}$ of the common angular interval in circular measure if Simpson's first rule is used, and by $\frac{3}{8}$ if Simpson's second rule is used. The result will be the moment of the figure relatively to the plane MPM. This moment, divided by the volume of the figure, will be the distance required.

The algebraical expression for the moment as found in this rule is

$$\int\int \frac{r^3}{3} \cos \theta dx d\theta.$$

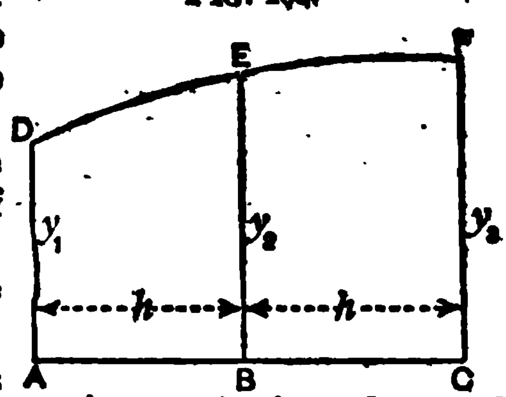
3rd. Determine the perpendicular distance of its centre relatively to a longitudinal plane passing through its edge, and a radius as PP^4BB^4, *by the foregoing rule, with the exception of multiplying by sines instead of cosines.*

Note.—In practice it is usual to defer the division of the cubes of the radii by 3 until after the addition of the products.

9. *To find the centre of gravity of a plane area contained between two consecutive ordinates, with respect to the near end ordinate.*

RULE.—To the sum of three times the near end ordinate, and ten times the middle ordinate, subtract the far end ordinate, and multiply the remainder by the square of the common interval. The product, divided by 24, will be the moment about the near end ordinate. On dividing this by the area, the longitudinal position of the centre of gravity is obtained.

FIG. 105.



Ex.: In fig. 105 let ABC be the base, and AD, BE, and CF the ordinates. Call them y_1, y_2, and y_3 respectively, and let the common interval be denoted by h. Then the moment of the area ABED about the

near end ordinate AD is equal to $\frac{(3y_1+10y_2-y_3)\times h^2}{24}$. If this be divided by the area of ABED (see p. 46), the quotient will be the distance of the C.G. from AD.

For an example, let the ordinates be 6·2, 8·5, and 9·4 feet, and the common interval 12 feet.

No. of Ordinates	Ordinates	Multipliers for Area	Products	Ordinates	Multipliers for Moments	Products
1	6·2	5	31·0	6·2	3	18·6
2	8·5	8	68·0	8·5	10	85·0
3	9·4	−1	−9·4	9·4	−1	−9·4
			89·6			94·2
		$\frac{\text{(Interval)}}{12}=$	1		$\frac{\text{(Interval)}^2}{24}=$	6
Area of portion included between 1 and 2			= 89·6	Moment about 1 = 565·2		

$$\frac{\text{Moment}\ \ 565\cdot2}{\text{Area}\ \ \ \ 89\cdot6}=6\cdot308$$ Perpendicular distance of centre of portion included between Nos. 1 and 2, from No. 1 ordinate.

Note.—When the moment of the area is required about the middle ordinate, the above multipliers should be changed to 7, 6, −1; so that moment = $\frac{7y_1+6y_2-y_3}{24}\times h^2$.

Moments of Inertia and Radii of Gyration.

1. *To find the moment of inertia of a body about a given axis.*

Rule.—Conceive the body to be divided into an indefinitely great number of small parts; multiply the mass (or area) of each of these small parts into the square of its perpendicular distance from the given axis: the sum of all these products as obtained will be the moment of the body about the given axis.

2. *To find the square of the radius of gyration of a body about a given axis.*

Rule.—Divide the moment of inertia of the body relatively to the given axis by the mass (or area) of the body.

3. *Given the moment of inertia of a body about an axis traversing its centre of gravity in a given direction, to find its moment of inertia about another axis parallel to the first.*

RULE.—Multiply the mass (or area) of the body by the square of the perpendicular distance between the two axes, and to the product add the given moment of inertia.

4. *Given the separate moments of inertia of a set of bodies about parallel axes traversing their several centres of gravity, to find the moment of inertia of these bodies about a common axis parallel to their separate axes.*

RULE.—Multiply the mass (or area) of each body by the square of the perpendicular distance of its centre of gravity from the common axis; the sum of all these products, together with all the separate moments of inertia, will be the combined moment of inertia.

5. *Given the square of the radius of gyration of a body about an axis traversing its centre in a given direction, to find the square of the radius of gyration about another axis parallel to the first.*

RULE.—Square the perpendicular distance between the two axes, and add the product to the given square of the radius of gyration.

6. *To find the moment of inertia of a plane area, bounded on one side by a curve* (see fig. 102), *relatively to its base line.*

RULE.—Divide the base line into a suitable number of equal intervals, and measure ordinates at the points of division; take the third part of the cube of each of these ordinates, and treat those quantities so computed as the ordinates of a new curve: the area of that new curve, found by the proper rule, will be the moment of inertia required. In algebraical symbols the above rule is expressed thus:—

$$\int \frac{y^3}{3}\,dx.$$

Note.—When the moment of inertia is required as a whole, and not in separate parts, it is usual to postpone the division of the cubes till the end of the calculation.

7. *To find the moment of inertia of a plane area, bounded on one side by a curve, relatively to one of its ordinates.*

RULE.—Multiply each ordinate by its proper multiplier, according to one of the rules for finding the area of such figures; then multiply each of the products by the square of the number of whole intervals that the ordinate in question is distant from the

ordinate taken as the axis of moments: the sum of these products, multiplied by $\frac{1}{3}$ or $\frac{3}{8}$ the cube of a whole interval, according as Simpson's first or second rule is used, will be the moment of inertia required.

In algebraical symbols this rule is expressed thus:—

$$\int x^2 y dx.$$

Example I.

CALCULATION OF MOMENT OF INERTIA OF THE QUADRANT OF A CIRCLE RELATIVELY TO THE BASE LINE.

No. of Intervals	Ordinates	Cubes of Ordinates / 3	Multipliers	Products
0	16·00	1365·33	1	1365·33
1	15·49	1238·89	4	4955·56
2	13·86	887·50	$1\frac{1}{2}$	1331·25
$2\frac{1}{2}$	12·49	649·48	2	1298·96
3	10·58	394·76	$\frac{3}{4}$	296·07
$3\frac{1}{4}$	9·33	270·72	1	270·72
$3\frac{1}{2}$	7·75	155·16	$\frac{1}{2}$	77·58
$3\frac{3}{4}$	5·57	57·29	1	57·29
4	0·00	0 00	$\frac{1}{4}$	0·00
				9652·76
			$\frac{\text{Interval}}{3} =$	$\frac{4}{3}$
				12870·34

Example II.

CALCULATION OF THE MOMENT OF INERTIA OF THE QUADRANT OF A CIRCLE RELATIVELY TO THE ENDMOST ORDINATE.

No. of Intervals	Ordinates	Multipliers	Products	Squares of Nos. of Intervals	Products
0	16·0000	1	16·0000	0·00	000
1	15·4919	4	61·9676	1·00	61·9679
2	13·8564	$1\frac{1}{2}$	20·7846	4·00	83·1384
$2\frac{1}{2}$	12·4900	2	24·9800	6·25	156·1250
3	10·5830	$\frac{3}{4}$	7·93725	9·00	71·4353
$3\frac{1}{4}$	9·3274	1	9·3274	10·5625	98·5207
$3\frac{1}{2}$	7·7460	$\frac{1}{2}$	3·8730	12·2500	47·4443
$3\frac{3}{4}$	5·5678	1	5·5678	14·0625	78·2972
4	9·0000	$\frac{1}{4}$	0·0000	16·0000	0·0000
					596·9288
				$\frac{\text{Interval}^3}{3} =$	$\frac{64}{3}$
				Approximate moment of inertia =	12734·4810

Definition.—If a body be conceived divided into an infinite number of parts, and the mass (or area) of each part be multiplied by the square of its distance from a fixed point, the sum of all these products is termed the polar moment of inertia about the point.

8. *To find the polar moment of inertia of a plane area about a point.*

(I) RULE.—At equal angular intervals sufficient to include the whole area, draw radii from the point to the perimeter. Treat the fourth power of these radii as the ordinates of a new curve having a common interval equal to the angular interval between consecutive radii expressed in circular measure. One quarter of the area of this curve, found by the proper rule, is the polar moment of inertia required.

Example.—Find the polar moment of inertia of a semicircle of 5 feet radius about one end of the diameter.

The polar radii at an angular interval of 15° are 10·00, 9·66, 8·66, 7·07, 5·00, 2·59 feet.

No.	Radius	$(\text{Radius})^4$	Multiplier	Product
1	10·00	10,000	1	10,000
2	9·66	8,735	4	34,940
3	8·66	5,624	2	11,248
4	7·07	2,498	4	9,992
5	5·00	625	2	1,250
6	2·59	45	4	180
7	—	—	1	—
	Common interval = ·2618			67,610
				$\times \frac{1}{3} \times \frac{1}{4} \times \cdot 2618$

Polar moment of inertia = 1,475

(II) RULE.—If the moments of inertia about two perpendicular axes through the point are known, their sum is equal to the polar moment of inertia about the point.

Definitions.—The product of inertia of an area about two perpendicular axes is the algebraic sum of each element of area multiplied by the product of its co-ordinates with reference to the two axes. In the first and third quadrants the product of inertia is positive; in the second and fourth quadrants it is negative.

The principal axes of inertia through a point are those axes about which the product of inertia is zero.

9. *Given the moments and products of inertia about two perpendicular axes, to find the corresponding quantities about any two other perpendicular axes.*

RULE.—If Ox, Oy (fig. 106) are the axes, X and Y the moments of inertia about them, and P their product, the moments and

product of inertia about Ox, Oy' (denoted by X', Y', and P'), making a positive angle θ with the original axes, are given by the following formulæ:—

$$X' = X\cos^2\theta + Y\sin^2\theta - 2P\sin\theta\cos\theta,$$
$$Y' = X\sin^2\theta + Y\cos^2\theta + 2P\sin\theta\cos\theta,$$

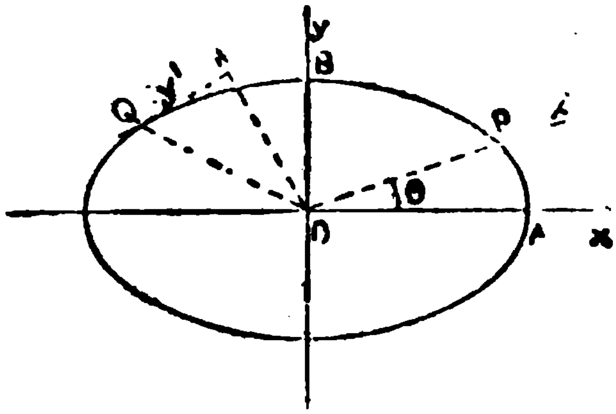
so that $X' + Y' = X + Y$; and

$$P' = P\cos 2\theta - \tfrac{1}{2}(Y - X)\sin 2\theta.$$

Note.—If Ox and Oy are principal axes, $P = O$, and the formulæ become

$$X' = X\cos^2\theta + Y\sin^2\theta;\ Y' = X\sin^2\theta + Y\cos^2\theta;$$
$$P' = -\tfrac{1}{2}(Y - X)\sin 2\theta.$$

FIG. 106.



If an ellipse (fig. 106) be drawn having its principal axes Ox, Oy along the principal axes of inertia, and of magnitude OA, OB equal to radii of gyration about Oy and Ox respectively, the radius of gyration about any other axis Ox' is represented by the perpendicular OM drawn to that tangent of the ellipse which is parallel to the axis Ox'; the moment of inertia about Ox' is proportional to the square of OM, or equally inversely proportional to the square of the radius OP along Ox'. The product of inertia about Ox', Oy' is similarly represented by the product of OM and MQ, where OQ is conjugate to OP.

10. *Given the moments and product of inertia about two perpendicular axes, to find the principal moments and axes of inertia.*

RULE.—If X, Y, and P are the moments and product of inertia respectively for the axes Ox, Oy, the angle θ (reckoned positively) made by the principal axes Ox', Oy', with the original axes is given by the formula—

$$\tan 2\theta = \frac{2P}{Y - X}$$

The magnitudes of the principal moments of inertia X′, Y′ about OX′, Oy′, are given by—

$$X' = \frac{Y+X}{2} - \sqrt{\frac{(Y-X)^2}{4} + P^2}; \quad Y' = \frac{Y+X}{2} + \sqrt{\frac{(Y-X)^2}{4} + P^2};$$

assuming X′ to be the least and Y′ the greatest moment of inertia.

11. *Given the moments of inertia about three axes, two perpendicular and one bisecting the angle between them, to find the principal moments and axes of inertia.*

RULE.—If X, Y, are the moments of inertia about the axes Ox, Oy, and Z that about an axis bisecting the angle yOx, the angle θ (reckoned positively) made by the principal axes Ox', Oy', with the original axes is given by the formula—

$$\tan 2\theta = \frac{Y + X - 2Z}{Y - X}$$

The magnitudes of the principal moments of inertia X′, Y′ about Ox', Oy', are given by—

$$X' = \frac{Y+X}{2} - \sqrt{Z^2 - Z(Y+X) + \frac{Y^2+X^2}{2}}$$

$$Y' = \frac{Y+X}{2} + \sqrt{Z^2 - Z(Y+X) + \frac{Y^2+X^2}{2}}$$

Note.—Since $X + Y = X' + Y'$, the sum of the moments of inertia about any two perpendicular axes is constant.

If the area has an axis of symmetry, the principal axes are along and perpendicular to this axis.

Ex.—An unequal-sided parallelogram is formed of two right-angled isosceles triangles of 1 inch side. Find the principal moments and axes of inertia.

Take Ox parallel to the shorter sides, and Oz perpendicular to the longer sides. Then $X = \frac{1}{12}$; $Y = \frac{1}{3}$; $Z = \frac{5}{24}$.

By the formulæ above $\tan 2\theta = -2$;

$\theta = -32°$ or $58°$, the former corresponding to the least moment of inertia.

$$\text{Greatest I or } Y' = \tfrac{1}{3} + \frac{\sqrt{5}}{24} = \cdot 218.$$

$$\text{Least I or } X' = \tfrac{1}{3} - \frac{\sqrt{5}}{24} = \cdot 032.$$

Table of Squares of Radii of Gyration of a few Special Figures.

Body	Axis	Radius² =
Rectangle; sides a and b	side a	$\frac{b^2}{3}$
	axis through C.G. parallel to side a	$\frac{b^2}{12}$
Square; side a	any axis through C.G.	$\frac{a^2}{12}$
Triangle; sides a, b, c; heights a', b', c'	side a	$\frac{a'^2}{6}$
	axis through C.G. parallel to side a	$\frac{a'^2}{18}$
Equilateral triangle; height d	any axis through C.G.	$\frac{d^2}{18}$
Trapezoid; height h, parallel sides a and b	side a	$\frac{h^2}{6} \cdot \frac{a+3b}{a+b}$
	axis through C.G. parallel to side a	$\frac{h^2}{18} \cdot \frac{a^2+4ab+b^2}{(a+b)^2}$
Trapezoid with two right angles; parallel sides a and b, perpendicular side h	side h	$\frac{1}{6}(a^2+b^2)$
	axis through C.G. parallel to side h	$\frac{a^4+2a^3b+2ab^3+b}{18(a+b)^2}$
Circle; diameter a	diameter	$a^2/16$
	centre (polar)	$a^2/8$
Ellipse; diameters a, b	diameter a	$\frac{b^2}{16}$
Common parabola; height a, base b perpendicular to axis	axis of parabola	$2b^2/5$
	base b	$8a^2/35$
	axis through C.G. parallel to base b	$12a^2/175$
Sphere; radius r	diameter	$\frac{2r^2}{5}$
	centre (polar)	$\frac{3r^2}{5}$
Spherical shell; external and internal radii r_1 and r_2	diameter	$\frac{2(r_1^5-r_2^5)}{5(r_1^3-r_2^3)}$
Ellipsoid of revolution; transverse semi-axis r	axis of revolution	$\frac{2r^2}{5}$
Ellipsoid; semi-axes a, b, c	axis $2a$	$\frac{b^2+c^2}{5}$
Circular cylinder; radius r, length $2a$	longitudinal axis	$\frac{r^2}{2}$
	transverse diameter through C.G.	$\frac{r^2}{4}+\frac{a^2}{3}$
Hollow circular cylinder; radius—external r_1, internal r_2; length $2a$	longitudinal axis	$\frac{r_1^2+r_2^2}{2}$
	transverse diameter through C.G.	$\frac{r_1^2+r_2^2}{4}+\frac{a^2}{3}$
Elliptic cylinder; semi-axes b, c, length $2a$	longitudinal axis	$\frac{b^2+c^2}{4}$
	transverse axis $2b$ through C.G.	$\frac{c^2}{4}+\frac{a^2}{3}$
Cone; height h, radius of base r	longitudinal axis	$\frac{3}{10}r^2$
	transverse axis through C.G.	$\frac{3}{80}h^2+\frac{3}{20}r^2$
	transverse axis through base	$\frac{h^2}{10}+\frac{3}{20}r^2$
	plane of base	$\frac{h^2}{10}$

Moment of inertia = square of radius of gyration × mass (or area) of the figure.

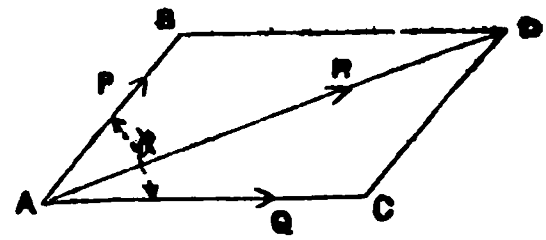
MECHANICAL PRINCIPLES.

RESULTANT AND RESOLUTION OF FORCES.

1. *To find the resultant of two forces acting through one point but not in the same direction.* (Fig. 107.)

Let AB, AC represent the two forces P and Q acting through the point A; complete the parallelogram ABCD: then its diagonal AD will represent in magnitude and direction the resultant of the two forces P and Q.

FIG. 107.



R = resultant. θ = angle P makes with Q.

a = angle R makes with Q. β = angle R makes with P.

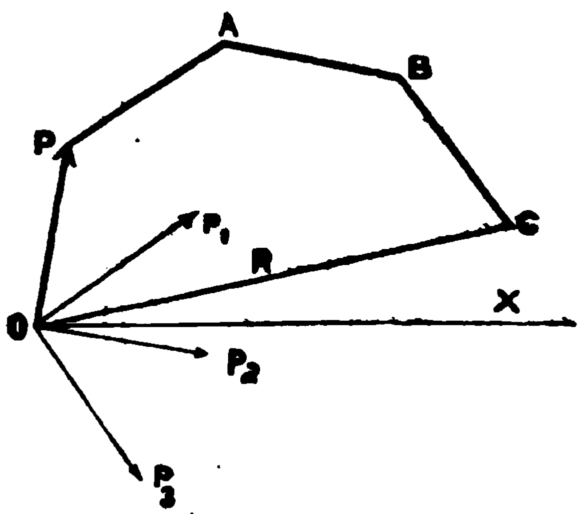
$$R = \sqrt{P^2 + Q^2 + 2.P.Q.\cos\theta};$$

$$\sin a = \sin \theta \frac{P}{R}; \quad \sin\beta = \sin\theta \frac{Q}{R}.$$

2. *To find the resultant of any number of forces acting in the same plane and through one point but not in the same direction.* (Fig. 108.)

Let P, P_1, P_2, P_3 be the forces acting through the point of application O; commence at O and construct a chain of lines OP, PA, AB, BC, representing the forces in magnitude and parallel to them; let C be the end of the chain: then a line R joining OC will represent in magnitude and direction the resultant of the forces P, P_1, P_2, and P_3.

FIG. 108.



Note.—This *geometrical* problem is true whether the forces act in the same or in different planes.

R = resultant.

θ = angle made by R with a fixed axis OX.

a, a_1, a_2, &c. = angles made by the forces P, P_1, P_2, &c., with OX.

ΣX = sum of the series of $P.\cos a + P_1.\cos a_1 + P_2.\cos a_2$, &c.

ΣY = sum of the series of $P.\sin a + P_1.\sin a_1 + P_2.\sin a_2$, &c.

$$R.\cos\theta = \Sigma X. \quad R = \sqrt{(\Sigma X)^2 + (\Sigma Y)^2}$$

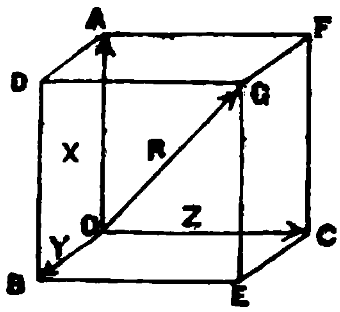
$$R.\sin\theta = \Sigma Y. \quad \tan\theta = \frac{\Sigma Y}{\Sigma X}$$

$$\cos\theta = \frac{\Sigma X}{R}$$

$$\sin\theta = \frac{\Sigma Y}{R}.$$

3. *To find the resultant of three forces acting through one point and making right angles with one another.* (Fig. 109.)

FIG. 109.



Let OA, OB, OC represent in magnitude and direction the forces X, Y, Z acting through one point O; complete the rectangular solid AEFB: then its diagonal OG will represent in magnitude and direction the resultant of the forces X, Y, Z.

R = resultant.

α, β, γ = the angles R makes with X, Y, Z, respectively.

$$Y = R \cdot \cos\beta. \quad R = \sqrt{X^2 + Y^2 + Z^2}.$$
$$Z = R \cdot \cos\gamma. \quad X = R \cdot \cos\alpha.$$

4. *To find the resultant of any number of forces acting through one point in different directions and not in the same plane.*

Let P, P_1, P_2, &c., be the forces α, β, γ; $\alpha_1, \beta_1, \gamma_1$; $\alpha_2, \beta_2, \gamma_2$, the angles their directions make with three axes passing through the point of application and making right angles with one another.

R = resultant.

$$\Sigma X = P \cdot \cos\alpha + P_1 \cdot \cos\alpha_1 + P_2 \cdot \cos\alpha_2 + \&c.$$
$$\Sigma Y = P \cdot \cos\beta + P_1 \cdot \cos\beta_1 + P_2 \cdot \cos\beta_2 + \&c.$$
$$\Sigma Z = P \cdot \cos\gamma + P_1 \cdot \cos\gamma_1 + P_2 \cdot \cos\gamma_2 + \&c.$$
$$R = \sqrt{(\Sigma X)^2 + (\Sigma Y)^2 + (\Sigma Z)^2}$$
$$\cos\alpha = \frac{\Sigma X}{R}$$
$$\cos\beta = \frac{\Sigma Y}{R}$$
$$\cos\gamma = \frac{\Sigma Z}{R}.$$

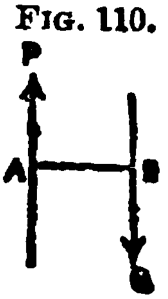
N.B. Cosines of obtuse angles are negative.

Note.—P cos α, P cos β, and P cos γ are termed the components of the forces in the directions of X, Y, and Z respectively. The components of the resultant are obtained by adding (allowing for sign) the components of the several forces in their respective directions.

PARALLEL FORCES.

A couple consists of two equal forces, as P and Q (see fig. 110), acting in parallel and opposite directions to one another, and is termed a right- or left-handed couple, according to whether the forces tend to turn in a clockwise direction or the reverse.

FIG. 110.



The moment of a couple is the product of either of the forces into the perpendicular distance AB between the lines of direction of the forces. The distance AB is termed the arm or lever of the couple.

5. *To find the resultant moment of any number of couples acting upon a body in the same or parallel planes.*

RULE.—Add together the moments of the right- and left-handed couples separately; the difference between the two sums will be the resultant moment, which will be right- or left-handed, according to which sum is the greater.

6. *To find the resultant of two parallel forces.* (Fig. 111 and 112.)

The magnitude of the resultant of two parallel forces is their sum of difference, according to whether they act in the same or contrary directions.

FIG. 111.

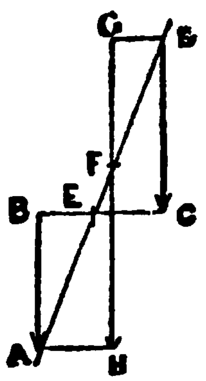
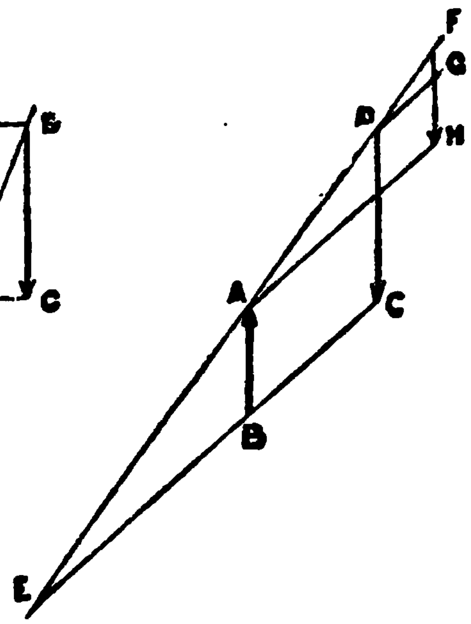


FIG. 112.



Let fig. 111 represent a case in which the two forces act in the same direction, and fig. 112 a case in which the components act in opposite directions.

Let AB and CD represent two forces; join AD and CB, cutting each other in E; in DA (produced in fig. 112) take DF =BA; through F draw a line parallel to the components; this will be the line of the resultant, and if two lines DG and AH be drawn parallel to BC, cutting the line of action of the resultant in G and H, GH will represent the magnitude of the resultant.

Or, numerically, the line of action of the resultant is obtained by adding (allowing for sign) the moments of the two forces about any point, this being equal to the moment of the resultant; the perpendicular distance of the line of action from the point is obtained by dividing this moment by the magnitude of the resultant.

$$\text{AF} = \frac{\text{DC . AD}}{\text{GH}} \qquad \text{DF} = \frac{\text{AB . AD}}{\text{GH}}$$

7. *To find the resultant of any number of parallel forces.*

RULE.—Take the sum of all those forces which act in *one* direction, and distinguish them as positive; then take the sum of all the other forces which act in the *contrary* direction, and distinguish them as negative. The direction of the resultant (positive or negative) will be in that of the greater of these two sums, and its magnitude will be the difference between them.

8. *To find the position of the resultant of any number of parallel forces when they act in two contrary directions.*

RULE.—1st. Multiply each force by its perpendicular distance from an assumed axis in a plane perpendicular to the

lines of action of the forces; distinguish those moments into right- and left-handed, and take their resultant, which divide by the resultant force: the quotient will be the perpendicular distance of that force from the assumed axis.

2nd. Find by a similar process the perpendicular distance of the resultant force from another axis perpendicular to the first and in the same plane.

9. *To find the resultant of any number of couples not necessarily in a plane.*

Two couples of equal moments in the same or in parallel planes are equivalent to one another, whatever the magnitudes and positions of the forces composing the couples may be. A couple is therefore conveniently represented by a line perpendicular to its plane, and of length proportional to its moment; usually the direction of the line is taken so that its relation to the direction of the couple is the same as that between the travel and the rotation of a right-handed screw. Note that any two parallel lines of the same magnitude and sense represent the same couple.

Rule.—Replace the couples by lines as above, giving them their correct magnitudes and direction, and treat these as forces through a point by Rule 4. The resultant gives the magnitude and direction of the resultant couple.

10. *To find the resultant of any number of forces in a plane.*

Rule.—Treat them as forces through any fixed point by Rule 2, and find their resultant. Calculate also the moment of each force about the point, and add them together allowing for the sign of each. The resultant moment divided by the magnitude of the resultant force gives the perpendicular distance of its line of action from the point.

Definition.—The moment of a force about a line that it does not meet is the product of the component of the force perpendicular to the line with the shortest distance between the line and the line of action of the force.

11. *To find the resultant of any number of forces, not in one place.*

Rule.—Resolve the forces parallel to three perpendicular axes as in Rule 4, and find the magnitude and direction of their resultant R. Calculate the moments of each component about the three axes, and treating these as couples find the resultant couple F by Rule 9. Resolve this couple into couples G parallel to the force R, and H perpendicular to R. Resolve the couple H into 2 forces R_1, R_2, of which R_1 is equal and opposite to R, while R_2 is equal and parallel to R; find the position of R_2 (not in plane of figure). Then the final resultant is equal to the force R_2 combined with the couple G (since R and R_1 neutralize). The combination of a force in and a couple about the same line is termed a *wrench*.

CENTRE OF GRAVITY.

1. *To find the moment of a body's weight relatively to a given plane.*

RULE.—Multiply the weight of the body by the perpendicular distance of its centre of gravity from the given plane.

2. *To find the common centre of gravity of a set of detached bodies relatively to a given plane.*

RULE.—Find their several moments relatively to a fixed plane; take the algebraical sum or resultant of those moments and divide it by the total sum of all the weights: the quotient will be the perpendicular distance of the common centre of gravity from the given plane.

Note.—When the moments of some of the weights lie on one side of the plane, and some on the other, they must be distinguished into positive and negative moments, according to the side of the plane on which they lie, and the difference between the two sums of the positive and negative moments will be the resultant moment. The sign of the resultant will show on which side the common centre of gravity lies.

Let w, w^1, w^2, &c. = the several weights.

d, d^1, d^2, &c. = the several perpendicular distances of the centres of gravity of w, w^1, w^2, &c., from the plane of moments.

D = the perpendicular distance of their common centre of gravity from the plane of moments.

$$D = \frac{wd + w^1d^1 + w^2d^2 + \&c.}{w + w^1 + w^2 + \&c.}$$

3. *To find the centre of gravity of a body consisting of parts of unequal heaviness.*

RULE.—Find separately the centre of gravity of these several parts, and then treat them as detached weights by the foregoing rule.

4. *To find the distance through which the common centre of gravity of a set of detached weights moves when one of those weights is shifted into a new position.*

RULE.—multiply the weight moved by the distance through which its centre of gravity is shifted; divide the product by the sum total of the weights: the quotient will be the distance through which the common centre of gravity has moved in a line parallel to that in which the weight was shifted.

Let w = weight shifted.

d = distance through which w was moved.

W = sum total of weights.

D = distance through which the common centre of gravity has moved in a line parallel to that in which the shifted weight was moved.

$$D = \frac{wd}{W}; \quad d = \frac{DW}{w}.$$

MOTION.

VELOCITY.

THE speed of a body or of a point within a body is the distance travelled in an infinitesimal space of time divided by that time. The velocity of the body takes also into account the direction in which the body is moving and is completely represented by a line drawn in the direction of motion, whose length represents to scale the speed.

Composition of velocities.—To combine several velocities impressed simultaneously upon a body, if OP, OP_1, OP_2, OP_3 (fig. 108, p. 76) represent the component velocities, draw PA parallel and equal to OP, AB, and BC parallel and equal respectively to OP_2 and OP_3. OC is the resultant velocity of the body. Similarly the resultant velocity OC may be resolved into two component velocities in any required directions X and Y by drawing lines from *od*, *do* parallel to X and Y; the lengths *od*, *do* represent the magnitudes of the component velocities.

Example.—If a boat is propelled at a speed and in a direction represented by AO (fig. 107, p. 76) in a stream whose velocity is represented by AB, the resultant velocity of the boat is represented by AD. To combine any number of velocities analytically, resolve each along three axes at right angles (or two if all the velocities are in one plane) by multiplying each velocity by the cosine of the angle which it makes with the axis; add, allowing for sign, the components along each direction. The sums are the components of the resultant velocity in the three directions, which may be compounded as above. E.g., if v_1, v_2, v_3, . . . are the velocities making angles α_1, α_2, α_3, . . . with the axis Ox, β_1, β_2, β_3 . . . with the axis Oy, and γ_1, γ_2, γ_3, . . . with the axis Oz, the components P, Q, R, of the resultant along Ox, Oy, Oz, are given by—

$$P = v_1 \cos \alpha_1 + v_2 \cos \alpha_2 + v_3 \cos \alpha_3 + \ldots$$
$$Q = v_1 \cos \beta_1 + v_2 \cos \beta_2 + v_3 \cos \beta_3 + \ldots$$
$$R = v_1 \cos \gamma_1 + v_2 \cos \gamma_2 + v_3 \cos \gamma_3 + \ldots$$

The resultant S is given by $S^2 = P^2 + Q^2 + R^2$; and it makes angles A, B, C, with the axis, given by—

$$\cos A = \frac{P}{S};\ \cos B = \frac{Q}{S};\ \cos C = \frac{R}{S}$$

Velocity diagram for a linked mechanism.—To find the velocity of any part of a linked mechanism, a velocity diagram may be drawn as illustrated in the following example. AOB represents diagrammatically (fig. 113) the crosshead of a screw-steering gear, AC, BD, the connecting links, and C and D are forced by guides to follow the axis of the frame OO. If the velocity of A is known, that of C (or any other part) can be found; and conversely.

Draw oa to represent the velocity of A, oa being perpendicular to OA. ob in the opposite direction represents that of B. The velocity of C relative to A is necessarily perpendicular to AC, while relative to the frame it is parallel to the axis. Therefore, draw ca perpendicular to CA, and oc parallel to the axis; this gives c. Similarly the point d is obtained. oc and od are the velocities of the points C and D. The velocity of any other point, say E in the connecting link AC, is obtained by dividing ac at e so that $ae : ec =$ AE : EC. Join oe, which is the velocity of the point E.

FIG. 113.

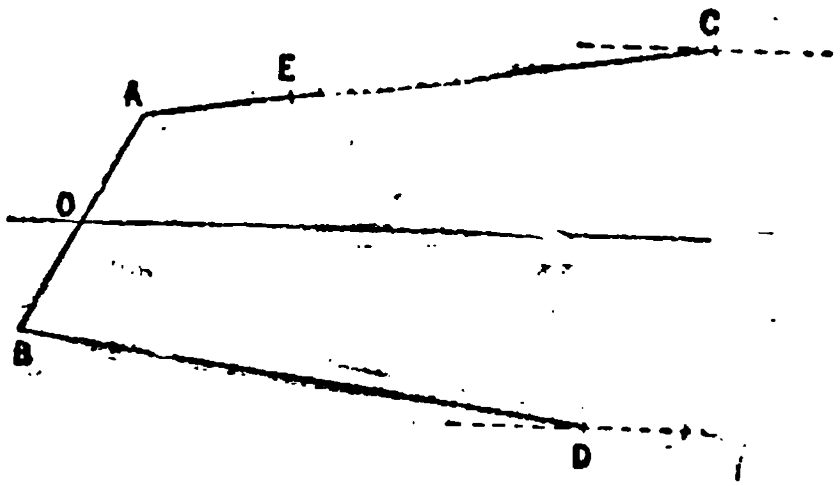
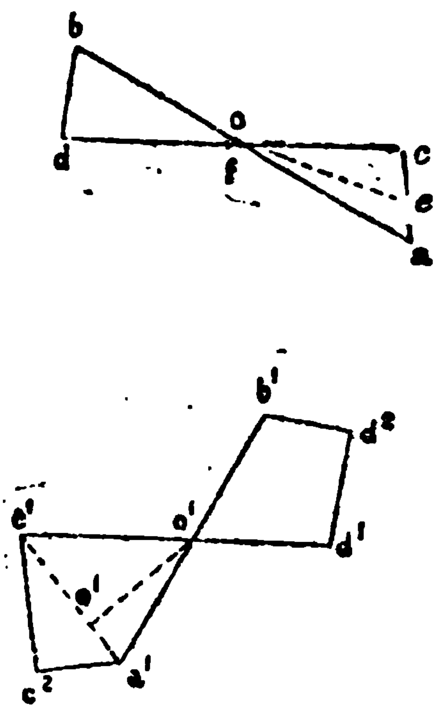


FIG. 114.



If f be the middle point of cd, of is the mean velocity of C and D, i.e. the velocity of the screw shaft as a whole, to allow for which a small amount of play has to be given. Note that the shaft is moving towards the crosshead, and that the velocities of C and D relative to the shaft are given by fo, df.

ANGULAR VELOCITY.

The angular velocity of a body about an axis is the angle turned through about the axis in an infinitesimal space of time divided by that time. It is usually expressed in radians per second or in revolutions per minute, the unit in the former case being $\frac{60}{2\pi}$ or 9·55 times that in the latter.

Composition and resolution of angular velocities.—The angular velocity about an axis may be represented by a line

drawn parallel to the axis, and of length proportional to the magnitude of the angular velocity. The direction of the line usually bears the same relation to the direction of rotation as that existing between the travel and rotation of a right-handed screw. When so represented, angular velocities are combined and resolved in the same way as linear velocities (see p. 81).

ACCELERATION.

The acceleration of a body is the rate of change of its velocity or the change of velocity in an infinitesimal space of time divided by that time. The velocity of a body comprises both its speed and its direction; hence the acceleration may generally be divided into two parts—(*a*) that due to increase of speed, which is represented by $\frac{dv}{dt}$, where v is the speed, and is tangential to the direction of motion; (*b*) that due to alteration of direction, which is directed normally towards the centre of curvature and is equal to v^2/ρ where ρ is the radius of curvature of the path.

Angular acceleration is the rate of increase of angular velocity; and, for a body revolving about a fixed axis, is represented by $\frac{d\omega}{dt}$ where ω is the angular velocity.

Composition of accelerations.—Accelerations, linear and angular, are combined and resolved similarly to velocities.

Acceleration diagram for a linked mechanism.—To find the acceleration of any part of a linked mechanism, a velocity diagram is first constructed as in fig. 113, p. 82. To find the accelerations of the steering gear shown, that of A, assuming the crosshead to revolve uniformly, is equal to $\frac{v^2}{\rho}$ or $\frac{oa^2}{\text{OA}}$, and may be represented by $o'a'$ parallel to AO. The acceleration $o'b'$ of OB is equal and opposite. The normal acceleration of C relative to A is represented by $a'c^2$ equal to $\frac{ac^2}{\text{AC}}$ and drawn parallel to CA; the tangential acceleration of C relative to A is represented by c^2c' drawn perpendicular to c^2a', the length of c^2c' being at present unknown. The acceleration of C relative to the frame OO is parallel to the axis; so that $o'c'$ is drawn parallel to the axis meeting c^2c' at c', giving the length of $o'c'$. Similarly the acceleration of D is found by drawing $b'd^2$, and d^2d', giving $o'd'$. That of any point E in the link AC is obtained by joining $a'c'$ and dividing it at e', so that $a'e : e'c' = \text{AE} : \text{EC}$. Join $o'e'$, which is the acceleration of the point E. The accelerations of C and D relative to the screw are equal to $\frac{1}{2}\, c'd'$.

DYNAMICS.

Relations between Force and Motion.

Ox, Oy, Oz = 3 perpendicular axes.
P, Q, R = component forces along Ox, Oy, Oz acting on a body.
u, v, w = component velocities along Ox, Oy, Oz.
m = mass of body.
M_x, M_y, M_z = momenta parallel to Ox, Oy, Oz respectively = mu, mv, mw.
f, g, h = component accelerations parallel to Ox, Oy, Oz.
g = acceleration due to gravity = 32·2 in foot-second units.

$$P = mf = m\frac{du}{dt} = \frac{dM_x}{dt} = m\frac{d^2x}{dt^2}\,;\quad Q = mg = m\frac{dv}{dt} = \frac{dMy}{dt} = m\frac{d^2y}{dt^2}\,;$$

$$R = mh = m\frac{dw}{dt} = \frac{dM_z}{dt} = m\frac{d^2z}{dt^2}$$

Note.—In the above, if m is in pounds, P, Q, R are in poundals, one poundal being equal $\frac{1}{g}$ pound or about half an ounce weight; if, on the other hand, the forces are expressed in pounds, the mass m must be expressed in terms of the gravitational unit equal to g (about 32) pounds.

Example.—A force of 2 lb. acts upon a mass of 3 lb. To find the acceleration.

The mass in gravitational units $= \frac{3}{g}$

$\therefore$ Acceleration $= \frac{P}{m} = \frac{2}{3/g} = \frac{2g}{3} = 21\frac{1}{3}$ ft. per second per second.

Angular Motion.

I = mass moment of inertia about axis of revolution.
ξ = angular acceleration.
ω = angular velocity.
θ = angle turned through.
M = angular momentum = $I\omega$.
G = moments of forces about axis.

$$G = I\xi = I\frac{d\omega}{dt} = I\frac{d^2\theta}{dt^2} = \frac{dM}{dt}$$

Note.—If G is expressed in foot-pounds, I must be expressed in the gravitational unit, or is I/g of the density of the material multiplied by the volume moment of inertia of the body (see pp. 69-75).

Work and Energy.

The work done by a force on a body is the product of the force by the distance moved resolved along the direction of the force. The work done by a couple is the moment of the couple

multiplied by the angle turned through resolved along the plane of the couple. With the previous notation, if the body runs through distances x, y, z parallel to the axes, and rotates through an angle θ, the work done is $Px + Qy + Rz + G\theta$, allowing for sign.

The energy of a body is its capacity for doing work.

Kinetic energy is energy due to motion. With the preceding notation, its amount is $\frac{1}{2g} m (u^2 + v^2 + w^2) + \frac{1}{2g} I\omega^2$, m and I being expressed in pounds and the result in foot-pounds.

Potential energy is energy due to position, and is measured from an arbitrarily fixed datum. A body of height h feet above the sea-level has potential energy of mh foot-pounds. A ship has potential energy due both to the height of its centre of gravity and the depth of its centre of buoyancy.

Molecular energy, due to heat, electrical state, magnetism, vibration, etc., is frequently waste energy as far as its capacity of doing useful work is concerned.

Conservation of energy. The work done on a body (other than that involved in a change in the potential energy) in a given interval of time is equal to the increase of its total energy.

Power is the rate of doing work. It is equal to $Pu + Qv + Ww + G\omega$, allowing for sign. This is equal to the rate of increase of energy. The practical unit of power is the *horse-power*, equivalent to 550 foot-pounds per second, or 33,000 foot-pounds per minute. Another unit is the *watt*, 746 of which are equivalent to one H.P.

Uniform Force in Line of Motion.

P = uniform force in pounds weight.
m = mass in pounds.
f = uniform acceleration = Pg/m.
V = initial velocity in feet per second.
s = distance travelled.
t = time occupied.
v = final velocity.
$v = V + ft$; $v^2 = V^2 + 2fs$; $s = Vt + \frac{1}{2}ft^2$.
For retarded motion change f to $-f$.
For motion vertically under gravity f to g or $-g$, according as the initial motion is downwards or upwards. In that case $P = \pm m$.
For motion down an incline of angle α to the horizontal, replace f by $g \tan \alpha$.
For angular rotation with the notation above, Ω being the initial angular velocity, $\omega = \Omega + \xi t$; $\omega^2 = \Omega^2 + 2\xi\theta$; $\theta = \Omega t + \frac{1}{2}\xi t^2$.

Gravity.

g = acceleration due to gravity in feet/second^2.
λ = latitude of the place.
h = height above sea-level.

R = radius of earth in feet = 20,900,000.

$$g = 32{\cdot}088\ (1 + {\cdot}005302\ \sin^2\phi - {\cdot}000007\ \sin^2 2\phi - \frac{2h}{R}).$$

Usually g is taken as 32·2, or 981 in centimetres/second².

Simple Vibration.

M = mass in pounds.
a = semi-amplitude of vibration.
n = frequency or number of double vibrations per second.
E = modulus or force in pounds required to produce unit extension.
t = time.
x = displacement at time 't.'
f = acceleration at time 't.'
α = a constant.
g = 32·2.

$$n = \frac{1}{2\pi}\sqrt{\frac{Eg}{M}};\ x = a \sin(2\pi nt + \alpha);\ f = -\frac{Eg}{M}x.$$

Simple Pendulum.

L = length of pendulum in feet.
T = time of a single small vibration in seconds.
g = acceleration due to gravity = 32·2.

$$T = \pi\sqrt{\frac{L}{g}} = {\cdot}554\sqrt{L}.$$

Table giving the Lengths of Pendulums in Inches that Vibrate Seconds in various Latitudes.

Sierra Leone	39·01997	New York	39·10120
Trinidad	39·01888	Bordeaux	39·11296
Madras	39·02630	Paris	39·12877
Jamaica	39·03503	London	39·13907
Rio Janeiro	39·04350	Edinburgh	39·15504

Table giving the Times of Vibration for Pendulum swinging through Large Arcs.

Angle swung on each side of vertical	30°	60°	90°	120°	150°	180°
Actual time of vibration ÷ Time for infinitely small angle	1·017	1·073	1·183	1·373	1·762	Infinite

Compound Pendulum.

κ = radius of gyration of body about axis of rotation.
h = centre of gravity below axis.
l = length of equivalent pendulum.

$$l = k^2/h.$$

The *centre of percussion,* or point at which a blow struck perpendicularly to the axis will cause no stress at the axis, is situated at a distance l (determined by the above formula) below the axis.

Centrifugal Force.

F = centrifugal force of body revolving in a circle at a uniform speed, or apparent force required to balance that necessary to produce the requisite normal acceleration.

W = weight of body.
N = number of revolutions per minute.
n = number of revolutions per second.
v = linear velocity in feet per second.
ω = angular velocity in circular measure per second.
r = radius of circle in feet.
g = acceleration due to gravity = 32·2 nearly.

$$\mathrm{F} = \frac{\mathrm{W}v^2}{gr} = \frac{\mathrm{W}r\omega^2}{g} = \frac{4\mathrm{W}n^2\pi^2r}{g} = \frac{\mathrm{W}n^2r}{\cdot 8154} = \frac{\mathrm{WN}^2r}{2935}$$

Gyroscopic Action.

If the axis of a revolving body is made to rotate into a new position, resistance is experienced due to the 'gyroscopic action' of the revolving mass. Let AB represent in the usual way the angular momentum Iω of a body having a moment of inertia I about the axis of revolution, and an angular velocity ω. If this axis is forced to occupy after a short time the position AC, BC represents the change of angular momentum. This is equal to Iω × $\angle$BAC. If this change is effected by turning the axis uniformly with angular velocity ω', the rate of change of angular momentum is I$\omega\omega'$, which is equal to the moment G of the applied couple. Note that the plane of G is perpendicular to that of shaft rotation, and of the direction of movement. If I is in weight units (lbs. × feet^2), and N and N$'$ are the number of revolutions per minute of shaft rotation, and of bodily rotation,

$$\mathrm{G} = \frac{\mathrm{I}}{g} \times \frac{4\pi^2\,\mathrm{NN}'}{3600} = \frac{\mathrm{I.N.N}'}{2935}$$

In the case of a ship going ahead with a right-handed screw, the forces required on the shaft when turning to starboard are downward aft and upward forward; the reaction on the hull is then such as to cause a slight trim by the bow.

Impact.

u_1, u_2 = the velocities of two bodies before impact (if moving in opposite directions make u_2 negative).
v_1, v_2 = the velocities after impact.
m_1, m_2 = the masses.
e = coefficient of restitution = ratio of velocity of separation to that of approach.

For direct impact,

$$v_1 = \frac{u_1(m_1 - em_2) + m_2 u_2 (1 + e)}{m_1 + m_2}$$

$$v_2 = \frac{u_1 m_1 (1 + e) + u_2 (m_2 - em_1)}{m_1 + m_2}$$

$$\text{Kinetic energy lost} = \frac{m_1 m_2 (u_1 - u_2)^2 (1 - e^2)}{2g (m_1 + m_2)}$$

Total momentum is unchanged, or $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$.

For oblique impact, resolve the velocities along and perpendicular to the line of impact; treat the components along the line by the above formulæ; the latter are unaltered by the impact.

The value of the coefficient e depends to some extent on the shape of the bodies and the velocity of impact, as well as on the material. Approximate values for the impact of like materials are given in the following table:—

Material	Cast Iron	Mild Steel	Soft Brass	Lead	Elm	Glass	Ivory
e	·70	·67	·38	·20	·60	·94	·81

HYDROSTATICS.

The *density* of a fluid is the weight of a unit volume. Generally it is stated in pounds per cubic foot, or inversely as the number of cubic feet required to weigh 1 ton. (See tables on p. 262.)

The *specific gravity* of a fluid is the ratio of its density to that of water.

Density of a Mixture of Two Liquids.

w_1, w_2 = densities of the two liquids.
w = density of the mixture.
m_1, m_2 = proportion of the two liquids in the mixture by volume.
n_1, n_2 = proportion of the two liquids in the mixture by weight.

$$n_1/n_2 = m_1 w_1/m_2 w_2 ; \quad w = \frac{m_1 w_1 + m_2 w_2}{m_1 + m_2} = \frac{n_1 + n_2}{\frac{n_1}{w_1} + \frac{n_2}{w_2}}$$

Pressure in a Liquid.

w = density of liquid in pounds per cubic foot.
z = depth below free surface.
p = intensity of pressure in pounds per square inch.
P = intensity of pressure in pounds per square foot.
$P = wz$; $p = wz/144$.

In salt water, $w = 64$, $P = 64z$, $p = \frac{4}{9}z$.

In fresh water, $w = 62{\cdot}5$, $P = 62{\cdot}5z$, $p = {\cdot}433z$.

If the *absolute* pressure be required P and p must be increased by 2120 and 14·7 respectively, in order to allow for the pressure of the atmosphere.

Note.—The *centre of pressure* of an immersed plane surface is that point on the surface through which the resultant pressure acts.

Pressure on Immersed Plane Surface.

If surface be vertical find the centre of gravity G and take axes Gx horizontal and Gy vertically downwards. Let

A = area of plane.
h = depth of centre of gravity below free surface.
w = density of fluid.
T = total thrust or pressure on plane.
$\bar{x}, \bar{y}$ = co-ordinates of the centre of pressure.

Then $T = wAh$

$$\bar{y} = \frac{1}{Ah}\int y^2 \,.\, dx \,.\, dy \text{ over area.}$$

$$= \frac{1}{Ah} \times \text{moment of inertia of area about } Gx.$$

$$\bar{x} = \frac{1}{Ah}\int xy\, dx\, dy \text{ over area.}$$

$$= \frac{1}{Ah} \times \text{product of inertia of area about } Gx,\ Gy.$$

If the surface and the axis Gy be inclined at an angle θ to the vertical, T and $\bar{x}$ are unaltered, but the value found for $\bar{y}$ should be multiplied by $\cos\theta$.

Pressure on any Closed Surface.

The resultant pressure on the whole immersed surface of a body is equal to the weight of the water displaced by the body and acts vertically upwards through the centre of gravity of the displaced volume. The upward force is termed the *displacement,* and the point through which it acts the *centre of buoyancy*.

DISPLACEMENT, Etc.

Computation of a Ship's Displacement.

This consists of computing the volume of the body of the vessel below the water-plane, up to which it is required to know her displacement, by one of the rules used for finding the volume of solids bounded on one side by a curved surface (see pp. 54, 55).

Two processes are generally made use of in computing a vessel's displacement, as the calculations in each process are required to determine the position of the centre of gravity of displacement, or centre of buoyancy, and also because the two results are a check on the correctness of the calculations.

One process consists in dividing the length of the ship on the load water-line by a number of equidistant vertical sections, computing their several areas by one of Simpson's rules, and then treating them as if they were the ordinates of a new curve, the base of which is the load water-line.

The other process consists in dividing the depth of the vessel below the load water-line by a number of equidistant horizontal planes parallel to the load water-line; the areas of their several planes are then computed by one of Simpson's rules, and those areas are treated as if they were the ordinates of a new curve, the base of which is the vertical distance between the load water-line and lowest horizontal plane.

As the vessel generally consists of two symmetrical halves, the volume of only half the vessel, below the load water-line, is calculated, the ordinates all being measured from a longitudinal vertical plane at the middle of the ship.

Usually the portion below the lowest water-line is treated, as are also the stern, rudder, bilges, keels, etc., as an appendage, its volume being calculated by means of equidistant vertical sections. The water-lines that are 'snubbed' or cut short abaft the fore perpendicular or before the after perpendicular are conceived to extend to these perpendiculars, the extra volumes thus introduced being regarded as negative appendages.

The displacement of a ship can also be obtained by dividing the length into sections, spaced as required by Tchebycheff's rule; the integration in a longitudinal direction is effected by simple summation. The water-lines are equidistantly spaced and integrated by Simpson's rules as before. This method is, generally speaking, more expeditious than is the one previously described, since fewer ordinates can be employed, and half the multiplication is dispensed with.

Both methods are illustrated in the displacement sheets given on pp. 94 ff.

DETERMINATION OF A SHIP'S CENTRE OF BUOYANCY FOR THE UPRIGHT POSITION.

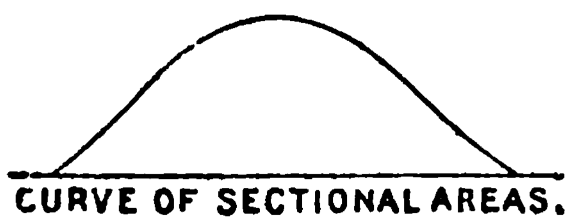
The centre of buoyancy is also termed the centre of gravity of displacement, as it occupies the same point as the centre of gravity of the volume of water displaced by the vessel, and its position is determined by the rules used for finding the centre of gravity of solids, bounded on one side by a curved surface (see rules, pp. 66 and 67), with the exception that its position need only be determined for its vertical distance from a horizontal plane, and its horizontal distance from a vertical plane; for the ship consisting of two symmetrical halves, it must necessarily lay in the longitudinal vertical plane in the middle of the ship.

Calculation of the centre of buoyancy is generally performed on the displacement sheet (see pp. 94 ff.).

CURVE OF AREAS OF SECTIONS.

This curve (see fig. 115) is of use in designing and in estimating the resistance of a ship, for it fixes the distribution of displacement along the length.

FIG. 115.



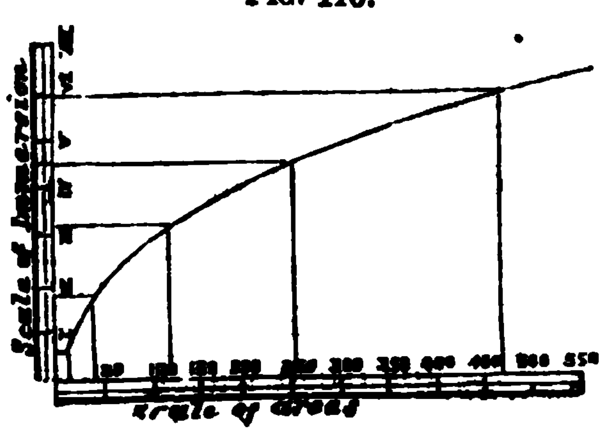
Method of Construction.—Compute the area of each transverse section up to the L.W.L.; and set it off to scale on a base of length. A curve drawn through the tops of the ordinates will form the curve required.

CURVE OF AREAS OF MIDSHIP SECTION.

This curve (see fig. 116) is used to determine the area of the immersed part of the midship section of a vessel at any given draught of water.

Method of Construction.—Compute the areas of the midship section from the keel up to the several longitudinal water-planes which are used for calculating the displacement; set these areas off along a base line as ordinates, in their consecutive order, the abscissæ of which represent to scale the respective distances between the longitudinal water-planes: a curve bent through the extremities of these ordinates will form the required curve.

FIG. 116.

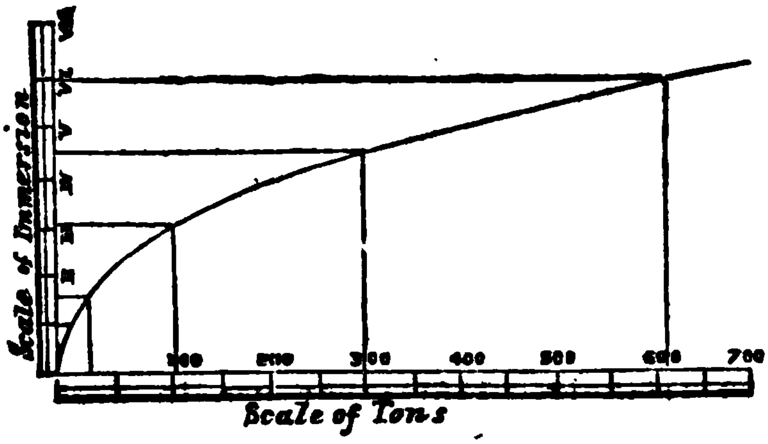


Curve of Displacement.

This curve is used to determine the displacement a vessel has at any draught of water parallel to the load water-line (see fig 117).

Method of Construction.—This curve is constructed in a similar manner to the foregoing curve, with the exception that the ordinates represent the several volumes of displacement (in tons of 35 cubic feet for salt water, and 36 cubic feet for fresh water) up to their respective longitudinal water-planes.

Fig. 117

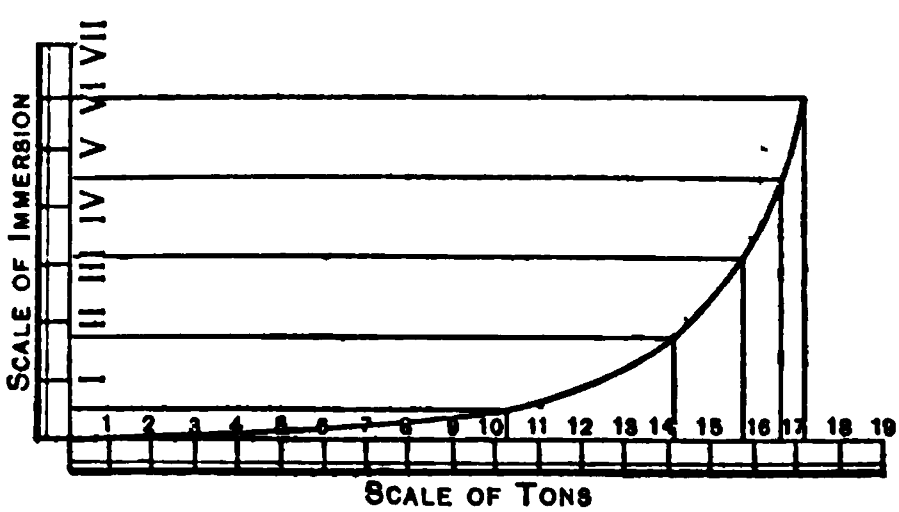


Curve of Tons per Inch of Immersion.

This curve (see fig. 118) is used to determine the number of tons required to immerse a vessel one inch at any draught of water parallel to the load water-plane.

To find the displacement per inch in cubic feet at any water-plane, divide the area of that plane by 12; and if the displacement per inch is required in tons, divide by 35 or 36, as the case may be.

Fig. 118.



A = area of longitudinal water-plane in square feet.
T = tons per inch of immersion at that water-plane.

$T = \frac{A}{12 \times 35}$ for salt water; $T = \frac{A}{12 \times 36}$ for fresh water.

Method of Construction.—This curve is also constructed in a similar manner to the two foregoing curves, with the exception that the ordinates represent to scale the tons per inch of immersion at the respective water-planes.

The coefficients of fineness of a vessel consist of the block coefficients (β), the prismatic coefficient (γ), and the midship section coefficient (μ). They are determined from the following equations:—

V = volume of displacement in cubic feet.

L = length of vessel at load water-line in feet (or length between perpendiculars, according to convention).

B = extreme immersed breadth in feet. (Occasionally this is taken as the breadth at L.W.L. in cases where this is less than the extreme breadth.)

D = mean draught of water in feet. (Take to top of keel if bar keel.)

Σ = Area of midship section up to L.W.L. in square feet.

$$\beta = \frac{V}{L.B.D.}; \ \gamma = \frac{V}{L\Sigma}; \ \mu = \frac{\Sigma}{B.D.}; \ \beta = \gamma . \mu.$$

Another coefficient sometimes used is that of water-line area (λ) given by $\lambda = \frac{A}{L.B.}$ where A is the area of the L.W.L. Usually this is expressed as a coefficient $\frac{L.B.}{\text{tons per inch}}$, this latter being equal to $\frac{420}{\lambda}$.

Values of these four coefficients for typical ships are given in the table below.

TABLE OF COEFFICIENTS OF FINENESS.

Class of Ship	Block Co-efficient $\beta=\frac{V}{LBD}$	Prismatic Coeffic't $\gamma=\frac{V}{L\Sigma}$	Mid. Sec. Coeffic't $\mu=\frac{\Sigma}{BD}$	Waterline Coeffic't $\lambda=\frac{A}{LB}$	$\frac{LB}{\text{Tons per Inch}}$
Battleship (modern) .	·60	·62	·965	·73	575
Battleship (older) .	·65	·68	·95	·81	520
First-class Cruiser .	·56	·62	·90	·68	620
Modern Light Cruiser .	·58	·63	·92	·76	550
Torpedo Boat Destroyer	·55	·67	·82	·76	550
Steam Yacht . .	·52	·565	·92	·69	610
Fast Passenger Steamer	·59	·62	·95	·70	600
Large Cargo Vessels .	·73	·77	·95	·83	510
Sailing Yacht . .	·2	·5	·4	·75	560
Tug	·58	·61	·95	·76	550

Note.—The 'length' in warships is the length between perpendiculars.

TABLE SHOWING METHOD OF COMPUTING A SHIP'S

Length between perpendiculars, 335 feet; breadth, 41 feet; draught at perpendiculars,

Number of Ordinate	Simpson's Multipliers	Appendage below lowest Water-line: Half Areas	Functions of Areas	Levers	Functions of Moments about 11	C.G. of Sections below 7 W.L.	Functions of Moments about 7 W.L.	WATER-LINES: 7 W.L.		6 W.L.		5 W.L.		4 W.L.		3 W.L.	
								SIMPSON'S MULTIPLIERS: ½		2		1		2		1	
1	½	—	—	10	—	—	—	—	—	—	—	·8 ·8	·4	·8 1·6	·4	·5 ·5	·25
2	2	—	—	9	—	—	—	—	—	1·76 3·52	3·52	2·6 2·6	5·2	3·0 6·0	6·0	3·1 3·1	6·2
3	1	·9	·9	8	7·2	·3	·27	1·6 ·8	1·6	3·5 7·0	3·5	4·66 4·66	4·66	5·3 10·6	5·3	5·7 5·7	5·7
4	2	2·05	4·1	7	28·7	·45	1·84	3·0 1·5	6·0	5·5 11·0	11·0	6·94 6·94	13·88	7·9 15·8	15·8	8·54 8·54	17·08
5	1	3·67	3·67	6	22·02	·48	1·76	4·6 2·3	9·2	7·64 15·28	7·64	9·4 9·4	9·4	10·5 21·0	10·5	11·2 11·2	11·2
6	2	5·24	10·48	5	52·4	·51	5·34	6·4 3·2	12·8	9·9 19·8	19·8	11·7 11·7	23·4	12·86 25·72	25·72	13·66 13·66	27·32
7	1	7·18	7·18	4	28·72	·54	3·87	8·46 4·23	8·46	12·04 24·08	12·04	13·9 13·9	13·9	15·04 30·08	15·04	15·8 15·8	15·8
8	2	9·68	19·36	3	59·28	·57	11·25	10·3 5·15	20·6	14·1 28·2	28·2	15·86 15·86	31·72	16·9 33·8	33·8	17·6 17·6	35·2
9	1	12·48	12·48	2	24·96	·6	7·5	11·96 5·98	11·96	15·6 31·2	15·6	17·34 17·34	17·34	18·4 36·8	18·4	19·0 19·0	19·0
10	2	14·3	28·6	1	28·6	·63	18·0	13·1 6·55	26·2	16·54 33·08	33·08	18·26 18·26	36·52	19·3 38·6	38·6	19·9 19·9	39·8
11	1	15·65	15·65	0	251·88	·66	10·33	13·6 6·8	13·6	17·1 34·2	17·1	18·7 18·7	18·7	19·7 39·4	19·7	20·26 20·26	20·26
12	2	15·7	31·4	1	31·4	·66	20·7	13·46 6·73	26·92	17·0 34·0	34·0	18·74 18·74	37·48	19·64 39·28	39·28	20·24 20·24	40·48
13	1	14·2	14·2	2	28·4	·65	9·22	12·5 6·25	12·5	16·2 32·4	16·2	18·06 18·06	18·06	19·2 38·4	19·2	19·9 19·9	19·9
14	2	11·35	22·7	3	68·1	·67	14·8	10·6 5·3	21·2	14·8 29·6	29·6	17·1 17·1	34·2	18·46 36·92	36·92	19·3 19·3	38·6
15	1	8·1	8·1	4	32·4	·69	5·58	8·3 4·15	8·3	12·8 25·6	12·8	15·4 15·4	15·4	17·0 34·0	17·0	18·1 18·1	18·1
16	2	5·72	11·44	5	57·2	·71	8·14	5·9 2·95	11·8	10·4 20·8	20·8	13·2 13·2	26·4	15·1 30·2	30·2	16·4 16·4	32·8
17	1	3·9	3·9	6	23·4	·73	2·88	3·7 1·85	3·7	7·3 14·6	7·3	10·3 10·3	10·3	12·64 25·28	12·64	14·34 14·34	14·34
18	2	2·63	5·26	7	36·82	·75	3·94	2·2 1·1	4·4	4·34 8·68	8·68	6·9 6·9	13·8	9·5 19·0	19·0	11·6 11·6	23·2
19	1	·54	·27	8	2·16	·3	·081	1·0 ·5	1·0	2·1 4·2	2·1	3·8 3·8	3·8	6·0 12·0	6·0	8·4 8·4	8·4
20	2	—	—	9	—	—	—	·76 ·38	1·52	·8 1·6	1·6	1·5 1·5	3·0	3·0 6·0	6·0	5·0 5·0	10·0
21	½	—	—	10	—	—	—	·76 ·38	·38	·76 1·52	·38	·76 ·76	·38	·76 1·52	·38	1·5 1·5	1·5
			200·0		279·88 251·88 28·00		125·47	197·54 98·77 6 592·62	+	284·94 569·88 5 2849·40	+	337·94 337·94 4 1351·76	+	375·88 751·76 3 2255·28	+	404·38 404·38 2 808·76	

N.B.—The dark figures are the ordinates; the light figures under them and also to their right are the products of the ordinates by their respective Simpson's multipliers, which are placed at the head and

13 feet for'd, 14 feet aft, 13 ft. 6 in. mean; waterlines apart, 2 feet; ordinates apart, 19 ft. 3 in.

2 W.L.		1 W.L.		VERTICAL SECTIONS				METACENTRES							
									Transverse		Longitudinal				
2		½		Functions of Areas	Multiples of Areas	Multipliers for Leverage	Moments	Ordinates of Load Water-line	Cubes of Ordinates	Functions of Cubes	Functions of Ordinates	Multipliers	Functions for C. of G. of W. Plane	Multipliers	Functions for Moment of Inertia of
·2 ·4	·1	—	—	3·3	1·65	10	16·5	—	—	—	—	10	—	10	—
3·16 6·32	6·32	3·3 1·65	6·6	23·19	46·38	9	417·42	3·3	36	72	6·6	9	59·4	9	534·
6·04 12·08	6·04	6·34 3·17	6·34	44·01	44·01	8	352·08	6·34	255	255	6·34	8	50·72	8	405·
8·94 17·88	17·88	9·26 4·63	18·52	66·29	132·58	7	928·06	9·26	793	1586	18·52	7	129·64	7	907·
11·66 23·32	11·66	11·94 5·97	11·94	88·47	88·47	6	530·82	11·94	1702	1702	11·94	6	71·64	6	429·
14·14 28·28	28·28	14·46 7·23	28·92	109·59	218·18	5	1095·9	14·46	3023	6046	28·92	5	144·60	5	723·
16·26 32·52	16·26	16·54 8·27	16·54	128·88	128·88	4	515·52	16·54	4525	4525	16·54	4	66·16	4	264·6
18·0 36·0	36·0	18·2 9·1	36·4	145·71	291·42	3	874·26	18·2	6029	12058	36·4	3	109·2	3	327·6
19·3 38·6	19·3	19·36 9·68	19·36	158·6	158·6	2	317·2	19·36	7256	7256	19·36	2	38·72	2	77·4
20·14 40·28	40·28	20·2 10·1	40·4	166·77	333·54	1	333·54	20·2	8242	16484	40·4	1	40·4	1	40·4
20·46 40·92	20·46	20·5 10·25	20·5	170·53	170·53	0	5381·3	20·5	8615	8615	20·5	0	710·48	0	0
20·5 41·0	41·0	20·5 10·25	41·0	170·24	340·48	1	340·48	20·5	8615	17230	41·0	1	41·0	1	41·0
20·24 40·48	20·24	20·3 10·15	20·3	165·64	165·64	2	331·28	20·3	8365	8365	20·3	2	40·6	2	81·2
19·7 39·4	39·9	19·9 9·95	39·8	157·57	315·14	3	945·42	19·9	7881	15762	39·8	3	119·4	3	358·2
18·7 37·4	18·7	19·04 9·52	19·04	144·17	144·17	4	576·68	19·04	6902	6902	19·04	4	76·16	4	304·6
17·2 34·4	34·4	17·76 8·88	35·52	126·83	253·66	5	1268·3	17·76	5600	11200	35·52	5	177·6	5	888·0
15·46 30·92	15·46	16·24 8·12	16·24	105·41	105·41	6	632·46	16·24	4283	4283	16·24	6	97·44	6	584·6
13·14 26·28	26·28	14·3 7·15	28·6	80·71	161·42	7	1129·94	14·3	2924	5848	28·6	7	200·2	7	1401·4
10·56 21·12	10·56	12·1 6·05	12·1	56·07	56·07	8	448·56	12·1	1772	1772	12·1	8	96·8	8	774·4
7·1 14·2	14·2	9·0 4·5	18·0	33·18	66·36	9	597·24	9·0	729	1458	18·0	9	162·0	9	1458·0
3·24 6·48	1·62	5·16 2·58	2·58	14·74	7·37	10	73·7	5·16	138	69	2·58	10	25·8	10	258·0
424·48 + 848·96 1 848·96		438·7 + 219·35 = 3706·78		= 3231·0			6344·06 5381·30 962·76			131488	438·7		1037·00 710·48 326·52		9860·2

(Continued on next page.)

ntegrated by the proper multipliers, and the sums of these products added together, the two sum will agree if the calculations are correct. In this case the sum thus obtained by two methods is 3231·0

$$\text{Displacement} - \text{main solid} = \frac{3231 \cdot 0}{35} \times \frac{8}{9} \times 19 \cdot 25 \times 2 = 3159 \text{ tons.}$$

$$\text{Moment below L.W.L.} - \text{main solid} = \frac{8706 \cdot 78}{35} \times \frac{8}{9} \times 19 \cdot 25 \times 4 = 17{,}026 \text{ ft.-tons.}$$

$$\text{Moment abaft} \ ⨯ - \text{main solid} = 962 \cdot 76 \times \frac{8}{9} \times (19 \cdot 25)^2 \times 2 = 18{,}121 \text{ ft.-tons.}$$

$$\text{Displacement} - \text{lower appendage} = \frac{200}{35} \times \frac{4}{3} \times 19 \cdot 25 = 147 \text{ tons.}$$

$$\text{C.G. below 7 W.L.} - \text{lower appendage} = \frac{125 \cdot 47}{200} = \cdot 63 \text{ feet.}$$

$$\text{Moment abaft} \ ⨯ - \text{lower appendage} = \frac{28}{35} \times \frac{4}{3} \times (19 \cdot 25)^2 = 395 \text{ ft.-tons.}$$

Item.	Tons.	Below L.W.L.		Abaft ⨯	
		Distance.	Moment.	Distance.	Moment.
Main solid	3159		17026		18121
Lower appendage	147	12·63	1857		395
Aft ,,	5·7	1·3	7	197·8	1127
Fore ,,	·6	6·0	4	− 193·6	− 116
Rudder	2·2	8·7	19	194·3	427
Bilge keels	·6	9·5	6	—	—
Shafting	3·2	6·3	20	153·8	492
Shaft brackets	1·2	6·5	8	168·5	202
Propellers	·9	6·7	6	173·1	156
Swell	·6	5·8	3	121·5	73
Recess	− 2·8	5·9	− 16	146·6	− 410
Negative appendage aft	− 7·0	11·2	− 78	176·0	− 1232
Total	3311·2	5·70	18862	5·8	19235

Displacement 3311 tons; C.B. 5·70′ below L.W.L., 5·8′ abaft ⨯.

$$\text{Area of L.W.L. (main portion)} = 438 \cdot 7 \times \frac{4}{3} \times 19 \cdot 25 = 11{,}260 \text{ sq. ft.}$$

$$\text{Moment abaft} \ ⨯ = 326 \cdot 52 \times \frac{4}{3} \times (19 \cdot 25)^2 = 161{,}300 \text{ ft.}^3$$

$$\text{Moment of inertia about} \ ⨯ = 9860 \cdot 24 \times \frac{4}{3} \times (19 \cdot 25)^3 = 93{,}700{,}000 \text{ ft.}^4$$

Item.	Area.	C.F. abaft ⨯	Moment about ⨯	Moment of Inertia about ⨯
Main portion	11,260		161,300	93,700,000
Appendage aft	100	198	19,800	3,900,000
Total	11,360	15·95	181,100	97,600,000

$$11{,}360 \times (15 \cdot 95)^2 = \underline{2{,}900{,}000}$$

$$\text{Moment of inertia about C.F.} = \underline{94{,}700{,}000} \text{ ft.}^4$$

Tons per inch $= \frac{11,360}{420} = 27 \cdot 0$.   C.F. abaft X $= 15 \cdot 95'$.

Longitudinal BM $= \frac{94,700,000}{3311 \times 35} = 818'$.   BG (with G in L.W.L.) $= 6'$ approx.

$\therefore$ Longitudinal GM $= 818 - 6 = 812$.

Moment to change trim 1 inch $= \frac{3311 \times 812}{12 \times 385} = 582$ ft.-tons.

Transverse BM $= \frac{131,488}{3311 \times 35} \times \frac{4}{3} \times \frac{1}{3} \times 19 \cdot 25 = 9 \cdot 78$ ft.

Area of midship section $= 170 \cdot 5 \times \frac{4}{3} \times 2 = 454$ sq. ft.

		'A.' W.L. (2 ft. above L.W.L.)				2 W.L.			3 W.L.		
No.	S.M	Ordinates.	Functions of Ordinates.	Cubes.	Functions of Cubes.	Ordinates.	Cubes.	Functions of Cubes.	Ordinates	Cubes.	Functions of Cubes.
1	½	—	—	—	—	·2	—	—	·5	—	—
2	2	3·45	6·90	41	82	3·16	31	62	3·1	30	60
3	1	6·65	6·65	294	294	6·04	220	220	5·7	185	185
4	2	9·55	19·10	871	1742	8·94	717	1434	8·54	623	1246
5	1	12·2	12·20	1816	1816	11·66	1581	1581	11·2	1405	1405
6	2	14·65	29·30	3144	6288	14·14	2833	5666	13·66	2549	5098
7	1	16·7	16·70	4657	4657	16·26	4291	4291	15·8	3944	3944
8	2	18·25	36·50	6078	12156	18·0	5832	11664	17·6	5452	10904
9	1	19·3	19·30	7189	7189	19·3	7189	7189	19·0	6859	6859
10	2	20·05	40·10	8060	16120	20·14	8181	16362	19·9	7881	15762
11	1	20·4	20·40	8490	8490	20·46	8552	8552	20·26	8316	8316
12	2	20·4	40·80	8490	16980	20·5	8615	17230	20·24	8292	16584
13	1	20·2	20·20	8242	8242	20·24	8300	8300	19·9	7881	7881
14	2	19·85	39·70	7821	15642	19·7	7645	15290	19·3	7189	14378
15	1	19·1	19·10	6968	6968	18·7	6539	6539	18·1	5930	5930
16	2	18·0	36·00	5832	11664	17·2	5088	10176	16·4	4411	8822
17	1	16·65	16·65	4616	4616	15·46	3690	3690	14·34	2950	2950
18	2	14·95	29·90	3341	6682	13·14	2274	4548	11·6	1561	3122
19	1	13·05	13·05	2222	2222	10·56	1174	1174	8·4	593	593
20	2	10·25	20·50	1077	2154	7·1	358	716	5·0	125	250
21	½	6·6	3·30	287	144	3·24	34	17	1·5	3	2
			446·35		134148			124701			114291

A.' W.L.

	Function of area.	*Mult.*	*Product.*	*Mult.*	*Moment.*
.W.L.	446·4	5	2232	7	3125
.W.L.	438·7	8	3510	6	2632
W.L.	424·5	−1	5742	−1	5757
			424		424
			5318		5333

Displacement of layer (L.W.L. to A.W.L.) $= 5318 \times \frac{4}{3} \times 19 \cdot 25 \times \frac{2}{12} \times \frac{1}{35} =$ 651 tons.

Moment about L.W.L. $= 5333 \times \frac{4}{3} \times 19 \cdot 25 \times \frac{4}{24} \times \frac{1}{35} =$ 652 ft.-tons.

	Tons.	*Moment below* L.W.L.
Up to L.W.L.	3311	18862
ayer L.W.L. to A.W.L.	651	−652
	3962	18210

Displacement to A.W.L. = 3962 tons.

C.B. below L.W.L. $= \frac{18210}{3962} = 4 \cdot 60'$

Tons per in. $= 446 \cdot 4 \times \frac{4}{3} \times \frac{19 \cdot 25}{420} = 27 \cdot 3$.

Transverse BM $= \frac{134148}{3962 \times 35} \times \frac{4}{3} \times \frac{19 \cdot 25}{3} =$ $8 \cdot 28'$.

2 W.L.

	Function of area.	*Mult.*	*Product.*	*Mult.*	*Moment.*
L.W.L	438·7	5	2194	3	1316
2 W.L.	424·5	8	3396	10	4245
3 W.L.	404·4	−1	5590	−1	5561
			404		404
			5186		5157

Displacement of layer (L.W.L. to 2 W.L.) =
$$5186 \times \frac{4}{3} \times 19{\cdot}25 \times \frac{2}{12} \times \frac{1}{35} =$$
694 tons.

Moment about L.W.L. =
$$5157 \times \frac{4}{3} \times 19{\cdot}25 \times \frac{4}{24} \times \frac{1}{35} =$$
680 ft.-tons.

	Tons.	*Moment about* L.W.L.
Up to L.W.L.	3311	18862
Layer L.W.L. to 2 W.L.	694	630
	2677	18232

Displacement to 2 W.L. = 2677 tons.

$$\text{C.B. below L.W.L.} = \frac{18232}{2677} = 6{\cdot}82'.$$

$$\text{Tons per in.} = 424{\cdot}5 \times \frac{4}{3} \times \frac{19{\cdot}25}{420} = 25{\cdot}9.$$

$$\text{Transverse BM} = \frac{124701}{2677 \times 35} \times \frac{4}{3} \times \frac{19{\cdot}25}{3} =$$
11·4′.

3 W.L.

	Function of area.	*Mult.*	*Product.*	*Mult.*	*Moment.*
L.W.L.	438·7	1	438·7	0	—
2 W.L.	424·5	4	1698·0	1	1698·0
3 W.L.	404·4	1	404·4	2	808·8
			2541·1		2506·8

Displacement of layer (L.W.L. to 3 W.L.) =
$$2541 \times \frac{4}{9} \times \frac{19{\cdot}25 \times 2}{35} = 1242 \text{ tons.}$$

Moment about L.W.L. =
$$2506{\cdot}8 \times \frac{4}{9} \times \frac{19{\cdot}25 \times 4}{35} = 2452 \text{ tons.}$$

	Tons.	*Moment about* L.W.L.
Up to L.W.L.	3311	18862
Layer L.W.L. to 3 W.L.	1242	2452
	2069	16410

Displacement to 3 W.L. = 2069 tons.

$$\text{C.B. below L.W.L.} = \frac{16410}{2069} = 7{\cdot}93'.$$

$$\text{Tons per in.} = 404{\cdot}4 \times \frac{4}{3} \times \frac{19{\cdot}25}{420} = 24{\cdot}7.$$

$$\text{Transverse BM} = \frac{114291}{2069 \times 35} \times \frac{4}{3} \times \frac{19{\cdot}25}{3} =$$
13·52′.

Explanation of Displacement Sheet (see pp. 94, 95).

The length of the ship between perpendiculars is divided into twenty equal intervals, and the immersed depth by seven equally spaced water-planes, the lowest being 2 feet above the keel amidships. Below 7 W.L. is treated as an appendage, it being preferable in all cases not to take the lowest W.L. down to or very near to the keel. The ordinates or half-breadths at the intersections of the vertical cross sections with the horizontal sections are measured off in feet, and set down in dark figures (usually in red) in rows opposite their ordinate number and under their W.L. number. Water-lines that are snubbed or cut away at the ends should be produced to the perpendiculars by eye for the purpose of these measurements; the volumes thus added are afterwards deducted as negative appendages.

The Simpson's multipliers (halved in order to reduce the labour of multiplication) are placed against the ordinate and water-line numbers; each ordinate is multiplied by the multiplier appropriate to its ordinate number, the result being placed on the right; it is also multiplied by the multiplier appropriate to its water-line, and the result is placed underneath.

Adding the former products in columns gives the functions of the water-planes; these are multiplied by the appropriate water-line multipliers, and the products then added, giving a number (3231·0 in the text) which is a function of the displacement. The displacement

of the main solid is obtained by multiplying this function $\frac{4}{9} \times \frac{1}{35} \times$ spacing of W.L.'s × spacing of ordinates; the factor $\frac{1}{9}$ is derived from Simpson's first rule applied twice in succession, the 8 is 2 for both sides of ship × 4 for the half multipliers used twice instead of the whole ones; the $\frac{1}{35}$ converts cubic feet into tons (for sea-water).

The functions of the water-planes are again multiplied by the number of intervals from the L.W.L.; the sum of the products (8706·78) being a function of the moment about the L.W.L. The multiplier — $\frac{8}{9} \times \frac{1}{35} \times$ (spacing of W.L.'s)^2 × spacing of ordinates — gives this moment in foot-tons.

Again, the products of the ordinates with the water-line multipliers are added in rows, the sums being functions of the transverse areas; these are multiplied by the appropriate ordinate multipliers, and the products added, giving the same function of the displacement (3231·0) as before. These products (headed 'multiples of areas') are further multiplied by the number of ordinate spacings from amidships (station 11); the products are added for each end of the ship, and the difference between the sums gives a function (962·76) of the moment of the main solid about amidships. On using the multiplier $\frac{8}{9} \times \frac{1}{35} \times$ spacing of W.L.'s × (spacing of ordinates)^2, the actual moment is obtained in foot-tons.

The lower appendage is dealt with by calculating the half-area of each transverse section below the lowest W.L., and the vertical position of its c.g. They are tabulated on the left, as shown. Each semi-area is multiplied by its Simpson's multiplier, and the result by the number of intervals from amidships; the functions of areas are also multiplied by the distances of their c.g. below 7 W.L. The three results are added in columns, allowance being made for the opposite signs of the two ends of the longitudinal moments, the sums are converted by the correct multipliers as shown. The remaining appendages are calculated by the ordinary rules for volumes and moments of solids, rough approximations being alone required. The 'recess' is that due to the emergence of the shafts. A table is set forth containing the displacements and moments of each item; the total displacement and the position of the centre of buoyancy are then found by simple summation and division.

To obtain the position of the longitudinal metacentre (see p. 188), each ordinate of the load water-plane is twice multiplied by the number of intervals from amidships. The difference between the sums of the first products for each ends (326·52) is a function of the moment; the multiplier — $\frac{2}{3}$ × (longitudinal interval)^2 — gives the moment of the main portion about amidships. The sum of the second products multiplied by $\frac{2}{3}$ × (longitudinal interval)^3 gives the moment of inertia of the main portion about amidships. Area of the main portion is obtained from the function of area (438·7) multiplied by the multiplier $\frac{2}{3}$ × longitudinal interval. In this case the appendage aft, being fairly large, has an appreciable effect; its area, moment, and moment of inertia are calculated (the last being equal to area × (distance of c.g. from amidships)^2) and inserted in a small table as shown. Thus the total area, the position of the centre of flotation (or c.g. of water-plane), and the moment of inertia about 11 are obtained. The correction necessary to find the inertia about the C.F. (see p. 70) is then introduced, and the longitudinal BM = moment of inertia about C.F. ÷ volume of displacement. By assuming an approximate vertical position for the c.g. of the ship, the moment to change trim 1 inch or $\frac{W \times GM\ (\text{long.})}{12\,L}$ is obtained. This, together with the position of the C.F., does not vary greatly with moderate changes of draft; and they are generally assumed constant.

The remaining particulars evaluated are the tons per inch (equal to area of water-plane ÷ 420), the area of midship section (equal to function of area for 11 × $\frac{2}{3}$ × water-line interval), and the transverse BM. To obtain the last, the cubes of the ordinates of the water-plane are multiplied by Simpson's multipliers, and the products added. The

sum multiplied by $\frac{1}{3}$ × longitudinal interval is equal to the moment of inertia of the water-plane about amidships; on dividing this by the volume of displacement, the transverse BM is obtained (see p. 111).

Frequently the displacement, tons per inch, transverse BM, and vertical position of the C.B. are required for other water-lines. Here they are worked out for 'A' W.L. (2 feet above L.W.L.), 2 W.L., and 3 W.L. The process consists of finding the volumes and moments of the layers between the respective W.L. and the L.W.L.; and adding to, or subtracting from, the displacement and moment for the L.W.L. The multipliers used at A.W.L. are 5, 8, −1 for volumes, and 7, 6, −1 for moments about middle ordinate (see pp. 46 and 68). For 2 W.L. the multipliers are 5, 8, −1 for volumes, and 3, 10, −1 for moments about end ordinate. For 3 W.L. the ordinary Simpson's multipliers are employed. When the after appendage is large, it is desirable to use the tons per inch and C.F., *both corrected for after appendage*, instead of the "functions of area" taken on p. 97. The transverse BM's are obtained by cubing the ordinates as for the L.W.L.

EXPLANATION OF DISPLACEMENT SHEET USING TCHEBYCHEFF'S RULE.

The horizontal water-lines are spaced equidistantly as with the preceding displacement sheet; an appendage is left below 7 W.L. The vertical transverse sections are spaced so as to meet the requirements of Tchebycheff's rule (see p. 46), using five ordinates for each half of the length, i.e. ten ordinates in all; the positions of the sections are indicated at the top of the sheet.* The ordinates are measured from the half-breadth plan; they are numbered I, II, III, IV, V for the fore end, commencing from amidships, and I A, II A, III A, IV A, V A for the after end, commencing from amidships. The half-breadths are measured off in feet and inserted in the table against the number of the corresponding ordinate, and under the corresponding water-line, in dark figures (usually in red). Under each water-line is set the correct Simpson's multiplier, halved for convenience; no multiplier is required opposite the ordinates.

The ordinates are first added in columns, the sums being functions of areas of the water-planes. These are multiplied by the corresponding Simpson's multipliers and their sum (1076·82) is a function of the displacement; the multiplier required to obtain the displacement in tons is 2 (for both sides) × $\frac{2}{3}$ (Simpson's rule for half multipliers) × $\frac{1}{35}$ (salt water) × water-line spacing $\frac{\times \text{length}}{10}$. The products of the functions of the water-line areas are also multiplied by the number of intervals from the L.W.L.; the results are functions of vertical moments. The sum of these multiplied by $\frac{4}{3} \times \frac{1}{35} \times$ (water-line spacing)$^2 \times \frac{\text{length}}{10}$ is the moment of the main solid about the L.W.L.

Each ordinate is afterwards multiplied by its appropriate water-line multiplier, and the products added in rows; the sums are functions of the areas of the transverse sections. The sum of these gives a function of the displacement, which should be the same as that previously obtained (1076·82). The differences between the functions of the areas for the fore and after ends, taken in pairs, are written down and multiplied by the levers equivalent to the Tchebycheff spacings expressed in terms of half the length; in the example the functions for the after body are greater in each case than the corresponding ones for the fore body, but, if this is not the case, allowance should be made for sign. The products are functions of moments about amidships; their sum multiplied by $\frac{4}{3} \times \frac{1}{35} \times$ water-line spacing $\times \frac{(\text{length})^2}{20}$ is the moment of the main solid about amidships expressed in foot-tons.

Unless a special body has been constructed with Tchebycheff sections, the calculation of the lower appendage is the same as that in the ordinary displacement sheet, equidistant sections being used.

* Alternatively the ordinary 'Simpson' sections numbered 2, 5, 7, 10, 12, 15, 17 and 20, may be taken instead of the exact sections required for Tchebycheff's rule with four ordinates repeated.

The remaining appendages are calculated as before; the final table has not been inserted in this case.

The calculation for the transverse metacentre is the same as before except that the cubes of the ordinates are added direct, and their sum multiplied by $\frac{2}{3} \times \frac{\text{length}}{10}$ to obtain the transverse moment of inertia.

For the centre of flotation, the differences of the ordinates in pairs are written down, allowing for sign if necessary, and multiplied by the Tchebycheff levers. The sum of the products is a function of moments; and the distance of the C.F. abaft amidships is equal to $\frac{\text{function of moments}}{\text{function of areas}} \times \frac{\text{length}}{2}$. The area of the water-plane is equal to function of area $\times 2 \times \frac{\text{length}}{10}$. To obtain the longitudinal moment of inertia, the ordinates are added in pairs, and multiplied by the squares of the Tchebycheff levers (·007, ·008, ·25, ·472, ·840). The sum of the products multiplied by a twentieth of the cube of the length is the moment of inertia about amidships. The corrections for the after appendage, and for the position of the C.F., and the calculation of BM are similar to those on the ordinary sheet.

The remaining calculations are made as before.

WEIGHT AND CENTRE OF GRAVITY OF SHIPS.

In the early stages of design, an approximation must be made to the weight of a ship in order to determine whether it is equal to the displacement assumed; the position of the centre of gravity is also required in order to determine the stability and trim.

The weight of a ship is conveniently divided into six items: hull, equipment, machinery, fuel, armour, and armament. In a merchant vessel the two last named are replaced by the load to be carried. The proportions vary greatly in different ships; those in the table are illustrative of certain types:—

Type of Ship.	Percentage Weight.					
	Hull.	Equipment.	Machinery.	Fuel (normal).	Armour.	Armament or Load.
Battleship	34	3	10	3½	31½	18
First-class Cruiser	38	4	17	7	20	14
Light Cruiser	43½	6	20	12	12½	6
T. B. Destroyer (deep condition)	34	4	34	25	—	3
Steam Yacht	61	10	19	10	—	—
Atlantic Liner	55	included in hull.	27	16	—	2 (Passengers and Stores)

HULL.

First Estimate.

The weight of hull is determined to a first approximation * in a variety of ways. In ships of very similar type it may be assumed to be the same percentage of the displacement, e.g. 34% in battleships, etc. Or it may be compared with the product length × (breadth + depth) amidships, the co-efficient being determined from a similar ship, making allowance for any great alteration of scantlings. Mr. J. Johnson (in Trans. Inst. Nav. Archs., 1897) published a useful method for approximating to the hull weight of a vessel built to the highest class at Lloyd's or Veritas.

If N = a modification of Lloyd's *old* longitudinal number
= Length from after part of stem to fore part of stern post on upper deck beams × {½ greatest moulded breadth + depth from top keel to top upper deck beams + ½ midships girth to upper deck stringer}.

In spar- and awning-deck vessels the girths and depths are measured to the spar or awning decks; they are taken to the main deck in one-, two-, and well-decked vessels.

W = finished weight in tons of the steel hull.

$$\text{Then } W = K\left(\frac{N}{100}\right)^{\chi}$$

$$\text{or } \log_{10} W = \chi \log_{10}\left(\frac{N}{100}\right) - \lambda.$$

Where χ and K or λ are determined from the table below:—

Type of Vessel.	χ	K	λ
Three deck	1·40	0·492	0·308
Spar deck	1·35	0·576	0·240
Awning deck	1·30	0·665	0·177
One-, two-, and well-deck . . .	1·30	0·856	0·068
Sailing	1·40	0·410	0·387

The distance of G abaft the middle of length and above the keel can be estimated from information available for other ships, taking these distances proportional respectively to the length and total depth.

Detailed Estimate.

In the later stages, when scantlings are fixed, the weight and centre of gravity of hull are found as follows:—

The hull may be divided into two groups: (1) calculable items forming about 60% (in a warship) of the whole, which include the greater part of the structure, and (2) 'judgment' items, including portions of complicated structure and fittings.

The latter can only be assessed by comparison with known weights in a similar ship (recorded weights if possible); the centre of gravity of each item can usually be determined

* See also under "Design".

with fair accuracy from its position. The former are directly calculated from the scantlings ; the manner of so doing is indicated in a few instances below. To each item 3% should be added for fastenings (or such an addition should be made at the end of the calculation).

If the stresses on the ship are also required, it is convenient to divide every item into portions wholly before and wholly abaft the midship section. Moments are taken about two fixed planes, one being generally the midship section and the other the L.W.L. or the keel.

Outer Bottom Plating.—Assume all of uniform thickness, repeating as necessary for the portions where the thickness is in excess or in defect of that assumed. Divide the length into sections spaced equidistantly, and measure the half-girths at each section. Apply the method of Rule II, par. 24, p. 58, obtaining the 'modifying factor' at each section. (This is the ratio of the slant length of the mean water-line intercepted between the sections to their perpendicular spacing.) Find the height of the centre of gravity of each section by dividing it into four equal parts, and proceeding as in par. 16, p. 62. Then arrange the calculations as in the following table for the forward portion of a warship below the armour deck, the percentage for laps, butts, and liners being taken as calculated for an average-sized plate (say $20' \times 4'$).

Transverse Framing.—There are usually several varieties, such as web and ordinary frames, or bracket, lightened plate, and watertight frames. To avoid calculating each one separately, calculate the weight and height of c.g. for a specimen frame at intervals of about $\frac{1}{10}$ length. Plot these as curves on a base of length of ship, drawing separate curves for each type of frame. The weight and c.g. position can then be read off for each frame, or a mean can be taken for a group of similar frames coming together.

Longitudinal Framing.—Usually uniform in section, but the height of c.g. must be taken at equidistant intervals, and the mean taken.

Bulkheads.—Main bulkheads are usually thicker towards the bottom, and the c.g. is below the centre of area. Take the minimum thickness of plating and calculate its weight and c.g. without any allowance. Then add the additional thickness, the stiffeners, and allowances for laps, butts, and fastenings ; all but the first item have the c.g. at centre of area. Then find the ratio of the initial to final weights, and of the c.g. below centre of area to the height of bulkhead. If this be done for one or two typical bulkheads, the rest may be determined from the simpler first calculation by allowing the same ratios. The ratio of weight for the main bulkheads of a warship is 1 : 1·9 ; for ordinary below-water bulkheads it is 1 : 1·66.

(Length of Ship = 400 feet).

WEIGHT AND CENTRE OF GRAVITY OF PART OF OUTER BOTTOM PLATING.

No. of Station.	Half-girth.	Modifying Factor.	Product.	Simpson's Multiplier (halved).	Function for Area.	Multiplier for Longitudinal Moment.	Product.	Depth c.g. of girth below L.W.L.	Product. *
1	21·0	1·03	21·6	$\frac{1}{2}$	10·8	5	54·0	·6	6·5
2	27·2	1·03	28·0	2	56·0	4	224·0	1·2	67·2
3	30·8	1·03	31·7	1	31·7	3	95·1	1·8	57·0
4	34·6	1·02	35·3	2	70·6	2	141·2	2·1	148·0
5	38·8	1·02	39·6	1	39·6	1	39·6	2·2	87·2
6	41·5	1·01	41·9	2	83·8	0	553·9	2·3	192·7
7	42·6	1	42·6	1	42·6	1	42·6	2·3	98·0
8	43·7	1	43·7	2	87·4	2	174·8	2·4	209·8
9	43·9	1	43·9	1	43·9	3	131·7	2·4	105·3
10	44·0	1	44·0	2	88·0	4	352·0	2·4	211·2
11	44·0	1	44·0	$\frac{1}{2}$	22·0	5	110·0	2·4	52·8
Sum.	Common interval 20 feet.				576·4		811·1		1235·5

Area (both sides) $= 576{\cdot}4 \times \frac{4}{3} \times 20 = 15{,}370$ sq. ft. Percentage for laps, etc., assumed 22; for fastenings 3. thick.

Weight $= 15{,}370 \times 20{\cdot}4 \times 1{\cdot}22 \times 1{\cdot}03/2240 = 176$ tons.

C.G. abaft No. 6 $= \frac{811{\cdot}1}{576{\cdot}4} \times 20 = 28{\cdot}2'$; i.e. C.G. is $100' - 28{\cdot}2'$ or $71{\cdot}8'$ before amidships (No. 11).

C.G. below L.W.L. $= \frac{1235{\cdot}5}{576{\cdot}4} = 2{\cdot}15'$.

* This column is the product of the preceding by the one headed 'Function for Area'.

For smaller bulkheads between decks, measure total length nd multiply by mean distance between decks. From this rea the weight of plating is at once found ; 12½% is a usual ercentage to add for laps. The length of the boundary ars is readily determined ; that of the stiffeners is found y dividing the area by their spacing, adding a percentage s necessary for brackets at heads and heels.

Decks.—Take in sections, each section having uniform hickness. Find area and longitudinal c.g. of each portion. Veight of plating is found as with bulkheads ; that of beams s equal to area × weight of beam per foot run ÷ beam pacing, adding a small allowance for beam knees or brackets. 'or planking, find volume of wood and multiply by its ensity, allowing about 6% for fastenings, e.g. a 3 in. deck reighs 14 lb. per square foot if of teak, 12 lb. if of fir, ncluding fastenings.

When all the items for the hull have been evaluated, they re tabulated in the manner shown in the succeeding pages. The calculations therein given are those for a paddle tug 45′ × 28′ × 11′ 4″ (4 feet freeboard) × 750 tons displacement.

SUMMARY OF

Note.—Base for vert

Item.	Tons.				
Outer bottom plating . .	64·5				
Bar keel	3·5				
Stem	·4				
Sternpost	·4				
Rudder, etc.	1·7				
Intercostal M.L. keelson	2·5				
Transverse bulkheads . .	15·0				
Transverse framing (ex webs)	27·0				
Cant frames	·6				
Deep beams and web frames	10·0				
Side keelsons and bilge stringers	8·5				
Top of reserve feed tank	2·3				
Upper deck	36·0				
Lower deck forward . .	5·0				
Lower deck aft	4·5				
Bridge deck	10·0				
Sponsons, etc.	12·5				
Paddle-boxes	12·0				
Coal-bunker bulkheads .	7·3				
Division in chain locker	·3				
Divisions in fresh-water and ballast tanks . .	·6				
Topsides	4·5				
Main engine bearers . .	14·5				
Auxiliary engine bearers	3·0				
Boiler bearers	1·5				
Carried forward . .	250·1	658·4		1050·4	2697·3

Item.	Tons.	Before 6. C.G.	Before 6. Mmt.	Abaft 6. C.G.	Abaft 6. Mmt.	Above base. C.G.	Above base. Mmt.
Brought forward.	250·1		653·4		1050·4		2397·3
Houses and fittings on and above bridge . .	3·5	15·5	54·2	—	—	27·0	94·5
Sponson houses . . .	4·5	2·5	11·2	—	—	18·5	83·2
Rubber	10·0	—	—	2	20·0	15·0	150·0
Companions	2·5	—	—	2	5·0	18·7	46·8
Skylights	2·0	—	—	·5	1·0	21·5	43·0
Engine and boiler casings	9·0	—	—	11·8	106·2	19·0	171·0
Steering gear	1·5	—	—	22·0	33·0	16·5	24·8
Ventilation	1·2	—	—	5·0	6·0	18·0	21·6
Pumping	1·5	8	12·0	—	—	10·0	15·0
Pillars	·5	—	—	5·0	2·5	12·0	6·0
Cathead	·4	61	24·4	—	—	21·0	8·4
Mooring pipes and chocks	3·2	—	—	—	—	19·0	60·8
Horn	·4	73	29·2	—	—	22·0	8·8
Towing hooks and stiffening	1·1	—	—	25·0	27·5	19·0	20·9
Towing beams and supports	·9	—	—	57·0	51·3	20·5	18·5
Bollards and fairleads .	12·0	—	—	7·5	90·0	16·5	198·0
Samson post	·5	64	32·0	—	—	18·0	9·0
Boats davits	2·2	—	—	22	48·4	22·0	48·4
Awning stanchions, etc.	·8	—	—	—	—	22·5	18·0
Ladders	1·0	—	—	—	—	15·0	15·0
Fittings in galley . .	1·2	—	—	13·0	15·6	17·0	20·4
W.C. fittings	·5	2·5	1·2	—	—	17·0	8·5
Fittings in other sponson houses	·3	16	4·8	—	—	17·0	5·1
Miscellaneous upper deck fittings	6·0	—	—	3·5	21·0	16·5	99·0
Shovelling flat	1·2	—	—	18·3	21·9	1·5	1·8
Side scuttles forward and aft	1·0	2·0	2·0	—	—	14·0	14·0
Side scuttles to sponson houses	·3	—	—	—	—	20·0	6·0
Coaling scuttles . . .	·6	—	—	18	10·8	15·3	9·2
Engineers store-room bulkhead	1·3	1·5	1·9	—	—	6·5	8·5
Cabin bulkheads forward	·5	33	16·5	—	—	12	6·0
Cabin bulkheads aft .	·9	—	—	48	43·2	12	10·8
Corticene on lower deck aft	·4	—	—	50	20·0	8·5	3·4
Silicate lagging . . .	·3	—	—	36·7	11·0	9	2·7
Chain locker fittings . .	·5	55	27·5	—	—	3	1·5
Fittings in—							
Fore crew space . .	1·0	55	55·0	—	—	12	12·0
After crew space . .	2·0	38	76·0	—	—	12	24·0
Cabins forward . . .	·6	32	19·2	—	—	12	7·2
Cabins and mess aft .	1·5	—	—	44	66·0	12	18·0
Cabin and saloon . .	1·5	—	—	48	87·0	12	18·0
Fore holds	1·5	45	67·5	—	—	5·5	8·3
After holds	1·5	—	—	48	72·0	5·5	8·3
Engineers' Stores . .	·5	—	—	—	—	7·0	3·5
Topside fittings . . .	1·5	—	—	—	—	18·0	27·0
Cement	8·0	—	—	3	24·0	1·1	8·8
Paint	4·0	—	—	—	—	10	40·0
	347·4		1038·0	2·14	1831·3 1038·0 746·3	11·0	3881·0

C.G. abaft 6, 2·14′. Above base, 11′.
Take 350 tons. 2·1′ abaft 6. 11′ above base.

EQUIPMENT.

This is conveniently divided (in warships) as follows: Fresh water (for 10 days allow about 8·7 tons for 100 men); provisions and spirits, including tare (for 4 weeks allow about 5·7 tons per 100 men); officers' stores and slops; officers, men, and effects (allow 8 to the ton); masts, rigging, sails, etc.; cables (500 fathoms); anchors; boats; warrant officers' stores (4 months); torpedo net defence.

In passenger ships undergoing long voyages allow 1 ton per 5 persons for passengers' gear, including baggage, bedding, etc., also ·025 ton per day per person (average) for water and provisions.

MACHINERY AND FUEL.

In the preliminary estimate the weight of machinery is based on the total power. Coefficients for various types of machinery are given on pp. 389, 390. Information obtained from actual ships should also be utilized where possible.

The weight of coal assumed is frequently an arbitrary amount less than the full bunker capacity. The full coal storage can be, however, determined from the volume of the bunkers calculated by the rules on p. 54, the areas of the sections being taken to underside of beams only. About 10 or 15 per cent (varying with type and shape of bunker) is then deducted for broken stowage; the net volume in cubic feet, on being divided by 43 (North Country coal), 40 (Welsh coal), 36 (patent fuel symmetrically stowed) or 45 (patent fuel shot into bunkers), gives the stowage in tons.

The weight of liquid fuel is equal to the whole volume in cubic feet divided by 38·5.

In all cases the centre of gravity of the fuel is the c.g. of the volume (see p. 66).

ARMOUR.

The weight and position of c.g. of armour in warships are determined by a process similar to that adopted for the hull. If the armour is not specified by its weight per square foot of plate, this can be determined from its thickness, since it weighs 495 lb. per cubic foot. Add 1½% for bolts. Backing is dealt with similarly to the planking of a teak deck.

ARMAMENT OR LOAD.

The weight of guns, mountings, charges, and projectiles are known (see pp. 380-385), and the position of the c.g. of each item can generally be spotted without difficulty. Allow 30 to 40% tare for cartridge cases.

The load in a cargo ship is generally determined beforehand. Its c.g. is usually found by assuming the whole space available to be filled with a homogeneous cargo—the assumption the most unfavourable to the stability; the c.g. is then that of the volume of the hold.

For passengers without baggage allow 16 to the ton with men, women, and children; 14 to the ton with men only. In pleasure steamers where the stability can be affected, assume the c.g. of passengers seated to be 6 inches above the seat; for those standing, 2 feet above the deck is generally a safe assumption.

The final weight and position of centre of gravity are found by adding together the weights and moments of the several portions as shown in the table below:—

SUMMARY OF BATTLESHIP WEIGHTS (580′ × 90′ × 27′ 6″ – 44′ deep).

Item.	Weight.	Moment from amidships.	Moment above L.W.L.	Moment below L.W.L.
Weight before amidships—	Tons.	Ft.-tons.	Ft.-tons.	Ft.-tons.
Armament	2076	236110	43020	1870
Armour	3270	353300	42077	1901
Hull	3770	355340	25473	28796
Machinery	820	29500	—	8200
Coal	670	23000	1360	5840
Equipment	400	55000	7420	766
		1052250		
Weight abaft amidships—				
Armament	2763	348020	46280	2190
Armour	3585	481250	28848	3563
Hull	4933	597170	24849	38897
Machinery	1930	198800	—	19300
Coal	330	21400	640	3060
Equipment	335	48200	3564	52
	24882	1694840	223531	114435
		1052250	114435	
		642590	109096	

Total weight of ship = 24882 tons.

C.G. abaft $\bowtie$ $= \dfrac{642590}{24882} = 25{\cdot}7$ feet.

C.G. above L.W.L. $= \dfrac{109096}{24882} = 4{\cdot}38$ feet.

STABILITY.

If a ship be slightly disturbed from a position of equilibrium, and if the forces then in operation tend to restore the original position, the equilibrium is termed *stable* ; if the forces tend to move it further from the original position, the equilibrium is termed *unstable* ; if it shows no tendency to move away from or return to the original position, the equilibrium is termed *neutral*.

The equilibrium of a ship is always stable as regards vertical deflections causing an alteration of displacement ; the only disturbances that need examination consist of inclinations about horizontal axes with the displacement unaltered. Of these the principal are : (*a*) inclination in a transverse plane about a longitudinal axis, and (*b*) inclination in a longitudinal plane about a transverse axis. The stability in these directions is termed transverse and longitudinal respectively.

TRANSVERSE STABILITY.

Fig. 119 is a transverse section of a ship heeled over through a certain angle θ. W′L′ is the water-line for the inclined position, and WL is the water-line for the upright position. These two planes intersect each other in a longitudinal direction, and bound two wedges L′SL and WSW′ equal in volume to each other, provided the displacement remains the same. The wedges are called respectively the wedges of *immersion* and *emersion*, or the *in* and *out* wedges. G is the centre of gravity of the ship and B′ her centre of gravity of displacement, or centre of buoyancy. The weight of the ship then acts vertically downwards through G, and the resultant pressure of the water acts vertically upwards through B′, these two forces forming a *righting couple*, the arm of which is GZ—that is, the perpendicular distance between the lines of action of the two forces. The moment of this couple—that is, the weight of the ship, or its displacement, multiplied by the length of the arm GZ—is the *moment of statical stability* of the ship at the given angle of inclination θ. This moment is generally expressed in *foot-tons*—that is, the weight of the ship in tons multiplied by the length of the arm GZ in feet. B is the centre of buoyancy of the ship when upright ; S is the point of intersection of the two water-lines, I the point where the vertical B′M cuts the plane of flotation ; g and g'

FIG. 120.

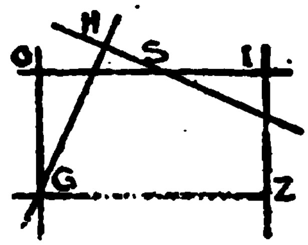
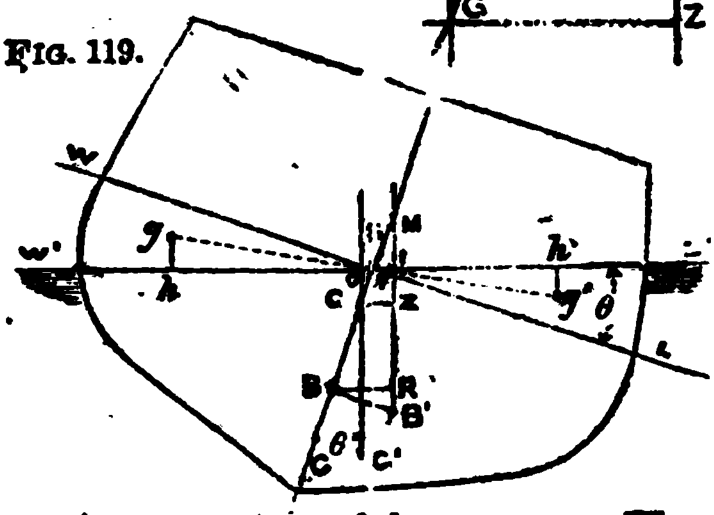


FIG. 119.



are the centres of gravity of the emerged and immersed wedges respectively, gh and $g'h'$ being perpendiculars dropped to g and g' from the plane of flotation W′L′. The point M, where the vertical line BM, drawn through the centre of buoyancy B when the ship is in an upright position, cuts the vertical line B′M, drawn through the centre of buoyancy B′ for the inclined position, is termed the *transverse metacentre* when the ship is inclined through an indefinitely small angle, and also when the point of intersection is the same for all angles of heel.

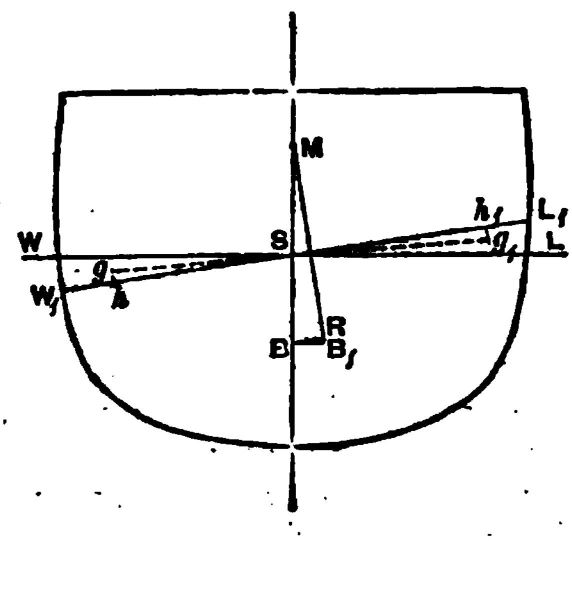
If the centre of gravity G is below the metacentre M, the equilibrium is stable; if G is above M, the vessel is unstable, and will capsize or at least heel to a large angle; if G coincides with M, the equilibrium is neutral.

The intersection of the new vertical through B′ is found usually to pass very near the metacentre M for all angles of heel up to 10° or 15°. Within these limits the stability lever GZ is equal to GM . sin θ; or the moment of statical stability is W . GM sin θ.

For moderate angles the stability depends wholly on the value of GM, which is termed the metacentric height. The position of G is calculated by the rules given on pp. 102-9; that of M is obtained by the process indicated below.

To obtain the height of the transverse metacentre.

FIG. 121.



Assume the angle of heel θ to be small, let

y = half breadth WS or SL at any station.
v = volume of either wedge WSW′ or LSL′.
g, g_1 = c.g.s. of the wedges.
h, h_1 = feet of perpendiculars from g, g_1 on WSL′.
V = volume of displacement.
I = moment of inertia of water-plane about longitudinal axis through S.
dx = an element of length of ship.

Then BR $= \frac{v}{V} . hh_1$.

Also $v . hh_1$ = moment of transference of wedges.

$$= 2\int \frac{y^2\theta}{2} . \frac{2y}{3} . dx \text{ approximately.}$$

$$= \tfrac{2}{3}\theta \int y^3 dx = \theta . \text{I}.$$

$\therefore$ BR $= \theta$. I/V.

Also BR $= \theta$. BM approximately.

Whence BM $= \frac{\text{I}}{\text{V}}$

The height of the transverse metacentre above the centre of buoyancy is equal to the moment of inertia of the water-plane area about the axis of inclination (in this case the centre line) divided by the volume of displacement.

The actual calculations for the transverse BM at several draughts of a ship are given in the displacement sheets on pp. 94, 100. The moment of inertia I is there expressed by the integral $\frac{2}{3}\int y^3 \, . \, dx$; the cubes of the ordinates are first integrated, and the result muliplied by the factor $\frac{2}{3}$.

In a ship whose sections are circular in the neighbourhood of the water-line, such as a submarine, the metacentre is coincident with the centre of the circular arcs.

Definition.—The *surface* stability of a ship is that obtained when the centre of gravity coincides with the upright centre of buoyancy.

Metacentric Diagram.

The stability of a ship in various conditions is conveniently exhibited by means of a metacentric diagram. In fig. 122, which shows the diagram for the ship taken in the displacement sheets (pp. 95, 97), and inclining experiment (pp. 135, 138), the vertical scale of draught is intersected by a straight line drawn at an angle of 45°. From the intersection of 'A.'W.L., L.W.L., 2 W.L., and 3 W.L., with this line are set up (or down) the vertical positions of the centres of buoyancy, and of the metacentres; these being obtained from the displacement sheets. Through the spots thus obtained are drawn the *curve of metacentres* and *curve of buoyancy*, giving the positions of M and B at intermediate water-lines.

The heights of the c.g. are calculated for a number of conditions of the ship; they are here shown for the inclining condition (see *inclining experiment*, p. 135), the legend (or normal) condition, deep load condition, and light condition. A cargo or passenger ship is frequently worked out for a large number of conditions as regards stowage of cargo, coal, and water ballast. From the curves the position of the metacentre at any water-line is obtained, and the vertical position of G marked on; the metacentric height is thus determined and recorded.

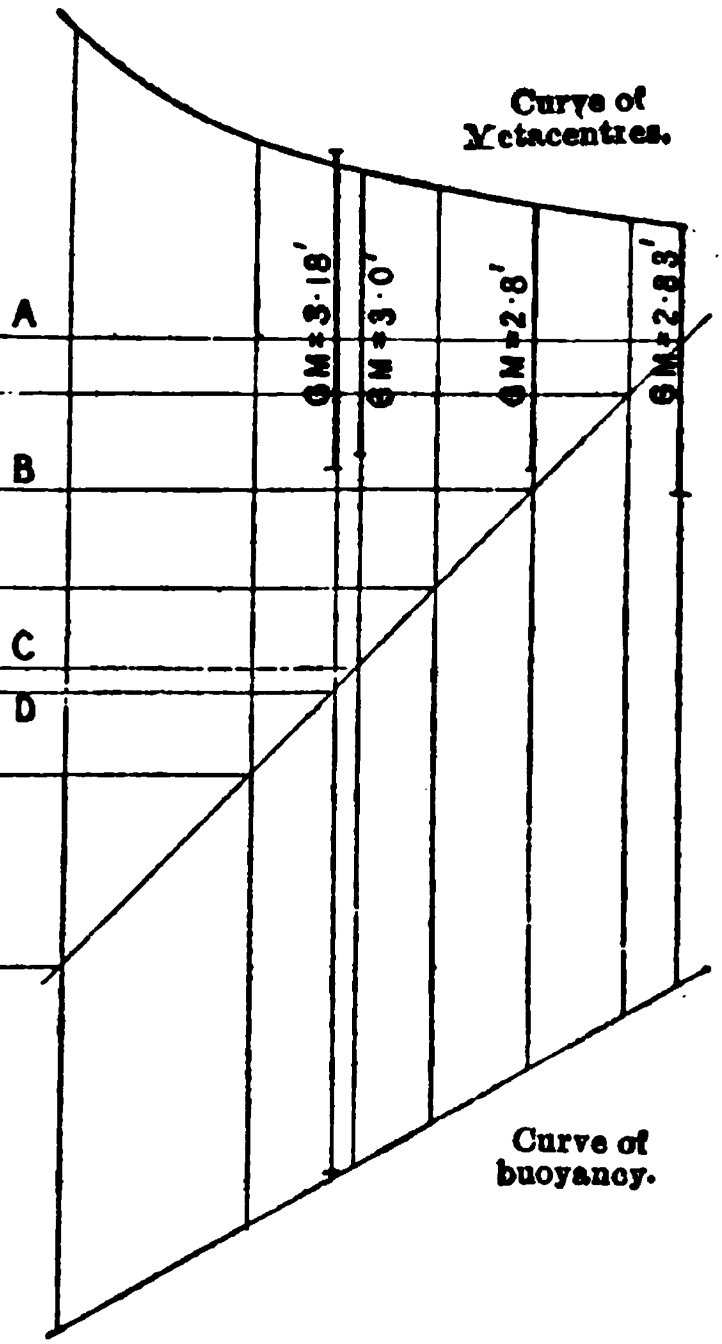
Value of GM in Typical Ships.

A vessel having a low metacentric height is termed *crank*; one provided with a large GM is termed *stiff*. A crank vessel usually rolls less and moves more easily among waves than a stiff vessel; for this reason the value of the GM adopted for a ship is made as small as possible, consistent with safety and other considerations. Typical values are given in the following table:—

FIG. 122.

METACENTRIC DIAGRAM OF SMALL CRUISER.

MEAN DRAUGHT	TONS DISPLACEMENT.	TONS PER INCH	
16-0½	4,140		A
15-6	3,864	27·65	
14-6	3,623	27·14	B
13-6	3,303	26·65	
12-7	3·031		C
12-3	2,947		D
11-6	2,677	26·15	
9-6	2,067	24·81	



A. Deep condition. Coal 725, oil 142, reserve feed 92 tons.
B. Normal condition. Coal 450 tons.
C. Light condition. No coal; no consumable stores.
D. Condition as inclined.

Note.—The curve of buoyancy is generally nearly straight; the tangent of its inclination to the horizontal is equal to

$$12 \times \text{depth of C.B. below W.L.} \times \frac{\text{Tons per inch}}{\text{Tons displacement}}$$

Type of Ship.	Minimum GM in feet.
First-class Battleships—Modern .	5·0
Do. Older types and Cruisers	3·5
Torpedo Boat Destroyers . . .	2·0
Torpedo Boats	1·5
Steamboats	1·0
Large Mail and Passenger Steamers	1·0 to 2·0* (maintained by water ballast)
Cargo-carrying Steamers . . .	2·0
Tugs	1·5
Shallow Draught Vessels	Very large.
Sailing Ships	1·5 to 6 (depending on sail area)

* In some very large modern liners the GM is greater; e.g. in *Aquitania* GM is 4 feet.

Approximate Formulæ for Height of Metacentre.

Depth of Centre of Buoyancy (Normand's Formula).

Depth of C.B. below water-line = $\frac{1}{3}$ mean draught +

$$\frac{\text{volume of displacement}}{3 \times \text{area of water-plane}}; \text{ or } \frac{1}{3} \text{ mean draught} + \frac{\text{displacement in tons}}{36 \times \text{tons per inch}}$$

Note.—If a bar keel is fitted, the mean draught should be taken to the top of keel.

Alternatively, this depth can be expressed as a percentage of the mean draught, which is about 42 for fine ships, 44 for ordinary battleships, and 46 for many merchant vessels.

Distance (BM) *between Centre of Buoyancy and Metacentre.*

$\text{BM} = \frac{(\text{greatest beam})^2}{\text{K} \times \text{draught}}$; where K is approximately 13 in battleships, 12 in light cruisers, destroyers, cargo, and passenger steamers, and 11 in steam yachts. In new designs it is advisable to take the value of K found in a similar ship.

Stability at Large Angles of Heel.

If the heel be so large that the vertical through B′ (fig. 119) no longer intersects the middle line at a fixed point, the metacentric method is no more applicable.

During the inclination of the ship the centre of buoyancy moves from B to B′, and B′ lies in a plane parallel to a line joining g and g'. The distance BB′ can be found from the following expression :—

$$\text{BB}' = \frac{v \times gg'}{\text{V}}$$

where V = volume of displacement and v = volume of either of the wedges ;

$$\text{BR} = \frac{v \times hh'}{V}, \text{ where BR is perpendicular to B'M;}$$

and $\text{GZ} = \text{BR} - \text{BG} \cdot \sin\theta = \frac{v \times hh'}{V} - \text{BG} \cdot \sin\theta,$

whence Atwood's formula for expressing the *moment of statical stability* at any angle θ is

$$M = W\left\{\frac{(v \times hh')}{V} - (\text{BG} \cdot \sin\theta)\right\}$$

The moment of *statical surface stability* at any angle θ is BR × W, being the righting moment obtained on the assumption that the c.g. of the ship coincides with B. The angle of heel in fig. 119 is BMB′ = LSL′, and its sine is equal to $\frac{\text{BR}}{\text{BM}} = \frac{\text{GZ}}{\text{GM}}$

Dynamical stability is defined to be the amount of mechanical work necessary to cause a body to deviate from its upright position, or position of equilibrium.

Dynamical stability is expressed as a moment by multiplying the sum of the vertical distances through which the centre of gravity of the ship ascends and the centre of buoyancy descends (i.e. the vertical separation of G and B), in moving from the upright to the inclined position, by the displacement.

In fig. 119 during the inclination of the ship through the angle θ, the centre of gravity has been moved through a vertical height GH − GO, and the centre of buoyancy has been lowered through a vertical distance B′I − BH, and the whole work to do this, or her moment of dynamical stability for the given angle θ, is

$$= W\{(\text{GH} - \text{GO}) + (\text{R'I} - \text{BH})\}$$
$$= W(\text{B'Z} - \text{BG}) = W(\text{B'R} - \text{BG} \cdot \text{vers}\,\theta)$$
$$= W\left(\frac{wv\,(gh + g'h')}{W} - \text{BG} \cdot \text{vers}\,\theta\right);$$

whence Moseley's formula for the moment of dynamical stability at any angle θ is

$$= wv(gh + g'h') - (W \times \text{BG} \cdot \text{vers}\,\theta),$$

where w is the density of water.

The dynamical stability of a ship at any angle θ is the *integral* of its statical stability at the given angle—that is, if M = the statical stability and U the dynamical stability, then

$$U = \int M d\theta,$$

where $d\theta$ is a very small angle of heel.

The *moment of dynamical surface stability* is expressed by multiplying the weight of the ship, or displacement, by the depression of the centre of buoyancy during the inclination —that is, for the angle θ

$$U = W(\text{B'I} - \text{BH}).$$

The Curve of Statical Stability is a curve used to record the value of the stability lever (GZ) of a vessel at any given angle of heel.

FIG. 123.

CURVE OF STATICAL STABILITY OF AN IRONCLAD WITH HIGH FREEBOARD

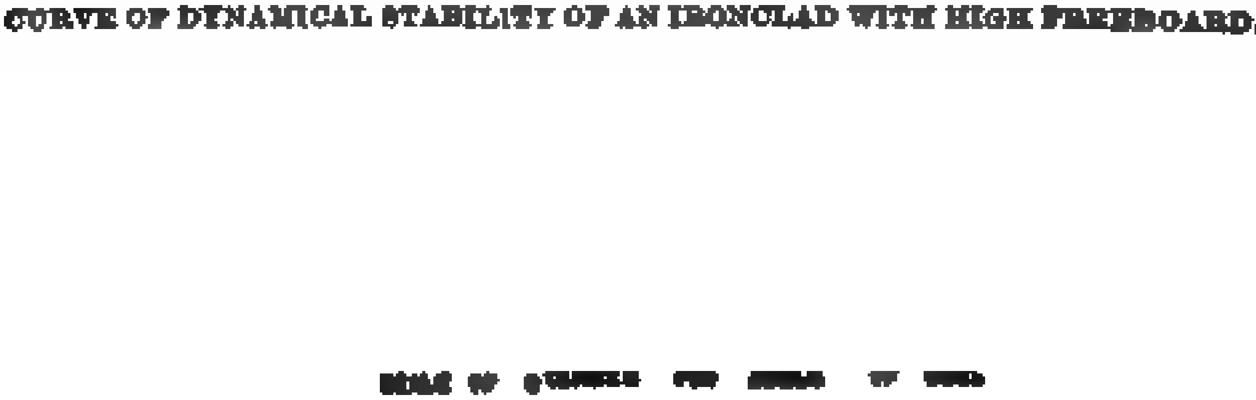
Method of Construction.—Calculate the length of the arm of the righting couple, or GZ (see fig. 119), for several successive angles of heel taken between the upright position and that at which the length of the arm becomes zero; set the lengths of these arms off as ordinates (see fig. 123) from a base line the abscissæ of which represent to scale the respective angles of heel: a curve bent through the extremities of these ordinates will form a curve of statical stability.

Note.—The length of the perpendicular at 57·3° (one radian) intercepted between the tangent at the initial portion of the curve and the base line is equal to the metacentric height.

The Curve of Dynamical Stability is constructed in a similar manner to that of the curve of statical stability, with the exception that the various lengths of the arm (B′Z — BG) = (B′R − BG vers θ) (see fig. 119) are taken as ordinates instead of GZ. Or preferably the curve is obtained by integrating the statical curve. The area up to each ordinate of the statical curve expressed in degrees × feet is divided by 57·3° and set up as an ordinate of the dynamical curve.

FIG. 124.

CURVE OF DYNAMICAL STABILITY OF AN IRONCLAD WITH HIGH FREEBOARD.

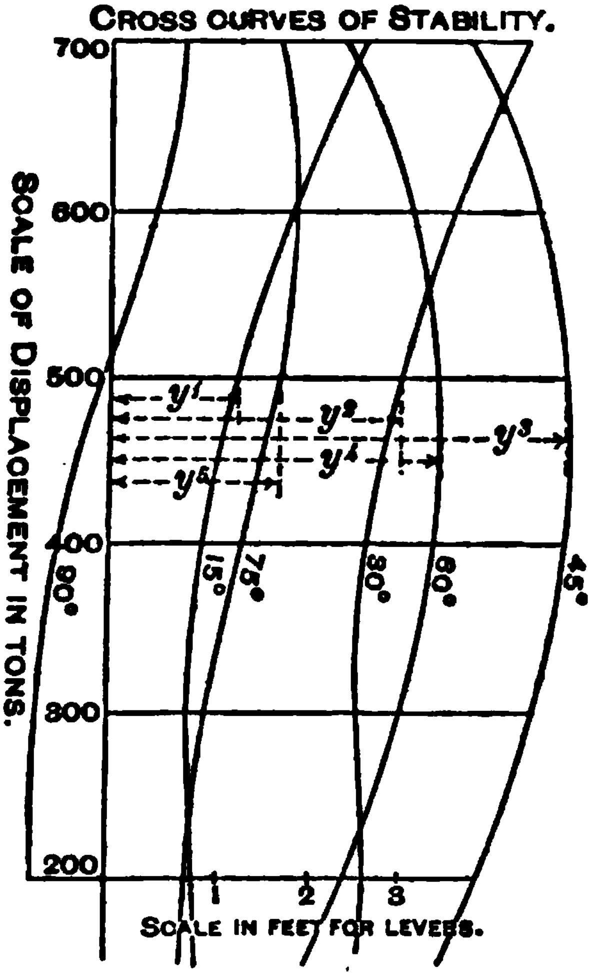


Note.—The angle at which the statical lever vanishes (and at which the dynamical lever is a maximum) is termed the *range* of stability.

Cross Curves of Stability.

These curves may be termed 'vertical curves of stability'; they consist of curves of righting levers at various draughts or displacements for certain fixed angles of heel. They hold a somewhat similar relation to the ordinary curves of stability as the body plan of a ship does to its water plane.

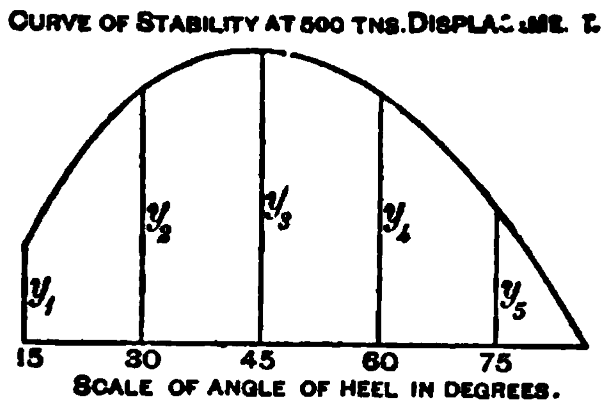
Fig. 125.



For cross curves (see fig. 125) the righting levers are calculated at certain fixed degrees of heel at various displacements, and the levers are set up as ordinates from an axis the abscissæ of which represent the displacement at which the levers for the fixed degree of heel are found.

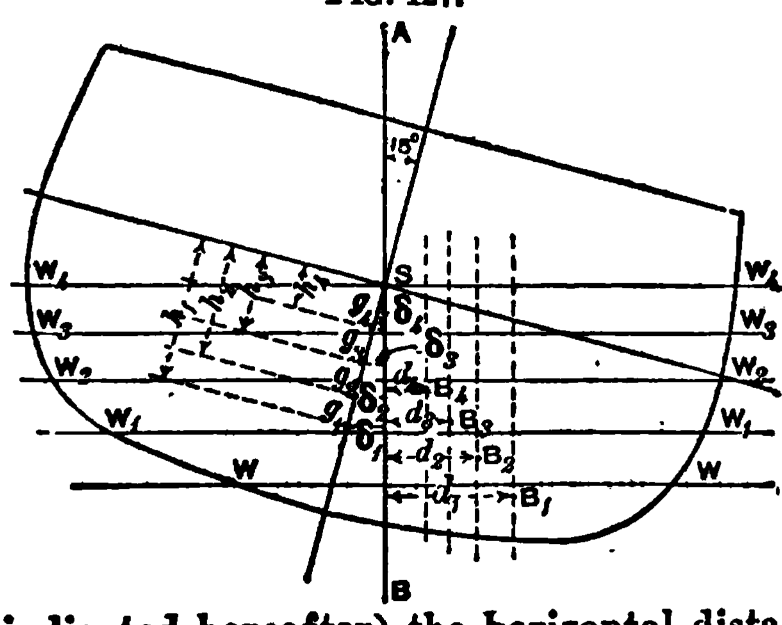
A number of such curves are constructed for various inclinations, and set off as in fig. 125.

Fig. 126.



For finding such curves at various draughts and angles of heel, say at 15° (see fig. 127), divide the body plan by a number of parallel planes representing various draughts of water or displacements.

Fig. 127.



Drop a perpendicular through the point where the highest water-line cuts the middle line of the ship, and then calculate (by the methods indicated hereafter) the horizontal distances d_1, d_2, d_3, etc., of

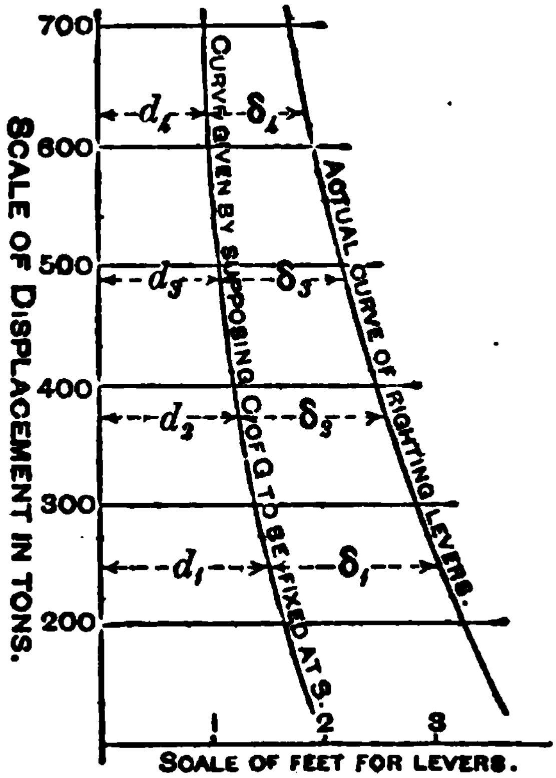
the centre of buoyancy up to each inclined water-plane from the vertical AB.

By assuming the centre of gravity to be at S, and fixed there for all draughts, the distances d_1, d_2, d_3, etc., would be the righting levers at the displacements, up to the respective water-planes W_1, W_2, W_3, W_4.

These lengths are then set off as ordinates along an axis having the several displacements up to the water-planes as abscissæ.

The actual righting levers can then be determined, when the correct positions of the centres of gravity corresponding to the various displacements are fixed, by multiplying the respective distances h_1, h_2, h_3, etc., of the actual centres of gravity g_1, g_2, g_3, g_4 below S by the sine of the angle of heel, and adding this length to the arms already found (see fig. 128).

FIG. 128.



The actual righting lever for the displacement up to W_4, W_4 would be equal to $d_4 + h_4 \sin 15° = d_4 + \delta_4$.

Up to W_3, W_3 it would be equal to $d_3 + h_3 \sin 15° = d_3 + \delta_3$, etc.

Should any of the centres of gravity be above the point S, a deduction would have to be made equal to the distance h of the centre of gravity above S multiplied by the sine of the angle of heel.

To Calculate the Statical and Dynamical Stabilities of a Vessel at Successive Angles of Heel.

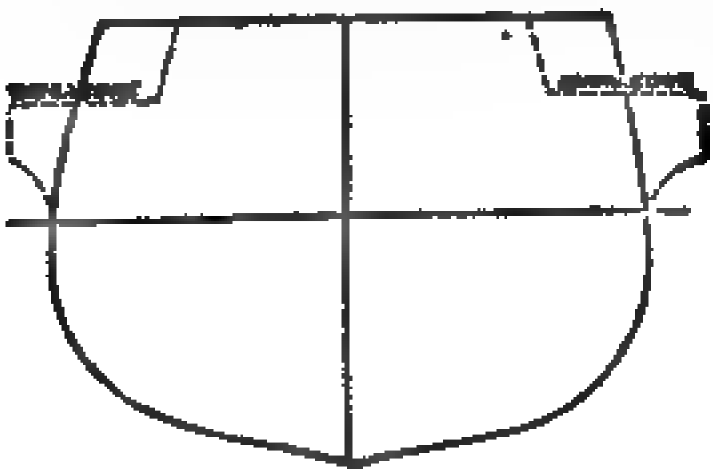
Among the various methods that are used for calculating the statical and dynamical levers, three are here described— (*a*) Barnes' method, (*b*) the direct method, (*c*) the integrator method; the last named is by far the quickest and most convenient. Either equidistant sections may be employed using Simpson's rule or specially spaced sections with Tchebycheff's rule (see displacement sheet, p. 100). The former may obviate the preparation of a special body plan, but the latter rule is generally more expeditious on the whole. It is generally assumed that all weights are fixed, all openings in the sides and decks closed and made watertight, all appendages can be neglected, and that no change of trim takes place during inclination.

Barnes' Method.

1. *Body Plan.*—Prepare a body plan (fig. 130) in which all the sections are taken perpendicular to the load water-line,

and at equal distances apart (if Tchebycheff's method be employed the sections are spaced as shown in the displacement sheet, p. 100). In constructing it the sections should be made fair continuous curves, any irregularities which might be caused by embrasures, etc., being left out (as shown in full lines in fig. 129, where the dotted lines show the actual section of vessel), they being treated separately afterwards as *appendages*. When there are appendages it is also necessary to have correct sheer and half-breadth draughts, in order to calculate their volume, etc.

FIG. 129.



2. *Angular Interval.*—The body plan has now to be crossed by a number of lines, radiating from the middle point of the load water-plane, and at equiangular intervals from 6° to 10°, arranging if possible that one passes through the edge of the upper continuous deck amidships.

FIG. 130.

The equiangular interval is determined as follows :—Divide the angle which the radiating line, passing through the edge of the upper deck, makes with the load water-line into such a number of equiangular intervals that the line passing through the edge of the upper deck becomes a stop-point in the integration to which these radiating lines will be afterwards treated. If Simpson's first rule is used the number of intervals must be even; if his second rule, a multiple of three must be used, and so on.

3. *Measuring the Ordinates.*—The ordinates of the immersed and emerged sides of the various inclined longitudinal water-planes are measured off right fore and aft for each successive angle of heel from the middle line of the ship, and entered upon a set of tables, styled *preliminary tables*, under their proper heading. One of these tables is necessary for each separate angle of heel.

4. *Preliminary Table.*—Three operations are performed (see p. 122) upon the ordinates entered in these tables. Firstly, they are affected by a set of Simpson's multipliers, in order

to find a function for the *area* of the immersed and emerged sides of the respective radial planes. Secondly, the squares of the ordinates are affected by the same set of multipliers in order to find a function for the *moment* of the immersed and emerged sides of the respective radial planes. Thirdly, the cubes of the ordinates are affected by the same set of multipliers in order to find a function for the *moment of inertia* of the immersed and emerged sides of the various radial planes about the middle line of ship.

5. *Combination Tables* (see p. 123).—The results obtained in the preliminary tables are made use of in these tables to determine—

(1st) The area of the various inclined water-planes, together with their centres of gravity.

(2nd) The volumes of the assumed wedges of immersion and emersion.

(3rd) The position of the true water-planes at the different angles of heel.

(4th) The moments of the corrected wedges of immersion and emersion.

6. *Areas of the Inclined Water-planes.*—The area of an inclined water-plane is easily found for any angle of heel by adding together the sums of the functions of the ordinates for the immersed and emerged sides of the respective water-planes, and multiplying the result by $\frac{1}{3}$ the longitudinal interval if Simpson's first rule is used.*

7. *Centre of Gravity of the Inclined Water-planes.*—To find the distance of the centre of gravity of any inclined water-plane relatively to the middle line of the ship, proceed as follows: —Take the difference between the sums of the functions of the squares of the ordinates for the immersed and emerged sides of the water-plane; divide the result by 2 and multiply the quotient by $\frac{1}{3}$ the longitudinal distance between the ordinates, if Simpson's first rule is used. That product divided by the area of the water-plane will give the distance of its centre of gravity from the middle line.

8. *Volumes of Assumed Wedges.*—Take the sums of the functions of the squares of the ordinates for both sides of each of the radial planes contained in the wedges of immersion and emersion, and enter them in their proper column in the combination table, and affect them by a proper set of multipliers; add their results together, subtract the lesser sum from the greater, and divide the result by 2. The quotient multiplied by $\frac{1}{3}$ the longitudinal distance between the ordinates, if Simpson's first rule is used (this division by 3 is generally done in the preliminary tables): this final product multiplied by $\frac{1}{3}$ of the equi-angular interval in circular measure, if Simpson's first rule is again

* *Note.*—The division by 3 is generally done in the preliminary tables.

used, will give the difference between the volumes of the assumed wedges of immersion and emersion. If there are any appendages the necessary additions or deductions are made here.

9. *Correcting Layer.*—If the volume of the assumed wedge of immersion exceeds that of the wedge of emersion, it shows that the displacement up to the radial plane is too great, and that to find the true water-plane a parallel layer must be taken away from the assumed wedges; but if the wedge of emersion exceeds that of immersion, a parallel layer must be added to the wedges.

The *thickness* of this layer is found by dividing the difference between the volumes of the two assumed wedges by the area of the proper radial water-plane, having made any additions or deductions in the case of appendages.

10. *Moments of Wedges for Statical Stability.*—The sums of the functions of the cubes of the ordinates for both the immersed and emerged wedges are placed in the proper column in the combination table, and are affected by the same set of multipliers as were determined for the sums of the functions of the squares; the products are multiplied by the various cosines of the angles of inclination made by the radial planes with the load water-line; the products are then added together and the sum divided by 3; the quotient is then multiplied by $\frac{1}{3}$ the angular interval, and that product by $\frac{1}{3}$ the longitudinal interval, between the ordinates, if Simpson's first rule has been used (this division by 3 is generally done in the preliminary tables): the final result will be the moment of the wedges about a line perpendicular to the radial plane, and passing through the middle point of the load water-plane. The corrections for the moments of the appendages must now be added or subtracted, as the case may be, also the correction for the layer, if any, must be done here, its moment being found by multiplying its volume by the distance of the centre of gravity of its water plane from the middle point of the load water-plane. If the centre of gravity of the layer lies towards that side for which the assumed wedge is the greater, the correction must be deducted; if it lies towards the opposite side, it must be added. This final result, being divided by the total volume of displacement, will give the length of the arm BR (see fig. 119). Multiply the height of the centre of gravity above the centre of buoyancy by the sine of the angle of heel, and subtract the product from BR; the remainder will be the length of the arm of the righting couple GZ; GZ multiplied by the displacement in tons will give the righting moment, or statical stability, of the ship for the given angle of heel.

11. *Moments of the Wedges for Dynamical Stability.*—This result is determined in a manner somewhat similar to that pursued for the statical stability, the only difference being that the

Preliminary Table for Stability at 30° Angle of Heel.

Nos. of Secs.	Ordinates	Multipliers	Functions of Ordinates	Squares of Ordinates	Multipliers	Functions of Squares	Cubes of Ordinates	Multipliers	Functions of Cubes
				Immersed Wedge.					
1	·8	½	·4	·6	½	·3	·5	½	·3
1½	8·1	2	16·2	65·6	2	131·2	531·4	2	1062·8
2	14·2	1	14·2	201·6	1	201·6	2863·3	1	2863·3
2½	17·8	2	35·6	316·8	2	633·6	5639·7	2	11279·4
3	20·5	1½	30·7	420·2	1½	630·3	8615·1	1½	12922·7
4	20·4	4	81·6	416·2	4	1664·8	8489·7	4	33958·8
5	20·2	2	40·4	408·0	2	816·0	8242·2	2	16484·4
6	20·2	4	80·8	408·0	4	1632·0	8242·2	4	32969·6
7	20·2	2	40·4	408·0	2	816·0	8242·2	2	16484·4
8	20·2	4	80·8	408·0	4	1632·0	8242·2	4	32969·6
9	20·2	1½	30·3	408·0	1½	612·0	8242·2	1½	12363·6
9½	20·3	2	40·6	412·0	2	824·0	8363·6	2	16727·2
10	18·8	1	18·6	353·4	1	353·4	6644·7	1	6644·7
10½	15·8	2	31·6	249·6	2	499·2	3944·3	2	7888·6
11	10·6	½	5·3	112·4	½	56·2	1191·0	½	595·5
			3)547·3			3)10502·6			3)204972·9
			182·4			3500·9	Immersed	.	68324·3
							Emerged	.	58590·4
							Both wedges		126914·7
				Emerged Wedge.					
1	1·1	½	·5	1·2	½	·6	1·3	½	·7
1½	6·5	2	13·0	42·2	2	84·4	274·6	2	549·2
2	10·9	1	10·9	118·8	1	118·8	1295·0	1	1295·0
2½	14·1	2	28·2	198·8	2	397·6	2803·2	2	5606·4
3	16·9	1½	25·3	285·6	1½	428·4	4826·8	1½	7240·2
4	20·0	4	80·0	400·0	4	1600·0	8000·8	4	32003·2
5	21·2	2	42·4	449·4	2	898·8	9528·1	2	19056·2
6	21·5	4	86·0	462·2	4	1848·8	9938·4	4	39753·6
7	21·2	2	42·4	449·4	2	898·8	9528·1	2	19056·2
8	20·1	4	80·4	404·0	4	1616·0	8120·6	4	32482·4
9	17·5	1½	26·2	306·2	1½	459·3	5359·4	1½	8039·1
9½	15·4	2	30·8	237·1	2	474·2	3652·3	2	7304·6
10	12·5	1	12·5	156·2	1	156·2	1953·1	1	1953·1
10½	8·9	2	17·8	79·2	2	158·4	705·0	2	1410·0
11	3·5	½	1·7	12·2	½	6·1	42·8	½	21·4
			3)508·1			3)9146·4			3)175771·3
			169·3			3048·8			58590·4

COMBINATION TABLE FOR STABILITY AT 30° ANGLE OF HEEL.

IMMERSED WEDGE

Angles of Heel	Functions of Ordinates	Functions of Squares of Ordinates	Multipliers	Products
0°	—	3015·4	1	3015·4
5°	—		4	12293·6
10°	—		2	6346·4
15°	—		4	13301·6
20°	—		2	7031·6
25°	—		4	15093·2
30°	189·4		1	3600·9

Immersed Wedge . . . 60682·1
Emerged Wedge . . 54148·8
2) 6533·3
3266·7
⅓ Angular Interval . . ·0291
32667
294003
65334
95·06097
Longitudinal Interval . . 30
Excess of Immersed Wedge 2851·83
Appendage . . 306·00
Area of Water-plane . 7197) 3157·83
Thickness of Layer . . ·33

CORRECTING LAYER

Moment for Statical Layer
=2387 × 1·16=2864.
Moment for Dynamical Layer
=2387 × ·16=387

EMERGED WEDGE

Functions of Ordinates	Functions of Squares of Ordinates	Multipliers	Products
—	3015·4	1	3015·4
—	2976·3	4	11905·2
—	2974·1	2	5948·2
—	2991·3	4	11965·2
—	3031·0	2	6062·0
—	3051·0	4	12204·0
169·3	3048·8	1	3048·8
			54148·8

INCLINED WATER-PLANE

Functions of ordinates {Immersed side 189·4; Emerged side . 169·3}
358·7
Longitudinal Interval . . 30
Uncorrected Area . . . 7028
Appendage 169
Total Area 7197

Functions of squares {Immersed side . 3600·9; Emerged side . 3048·8}
2) 552·1
276·05
Longitudinal Interval . . 30
Uncorrected Moment . . 8281
Moment for Appendage . 8058
Area of Water-plane . 7197) 8339
C. of G. towards immersed side 1·16

BOTH WEDGES

Statical Stability

Sums of Functions of Cubes	Multipliers	Products	Cosines of Heel	Products for Moments
111479·3	1	111479·3	·8660	96540·1
114440·9	4	457763·6	·9063	409493·4
115141·4	2	230282·8	·9397	216396·7
120240·2	4	480960·8	·9659	464531·4
127258·5	2	254517·0	·9848	250648·3
135890·3	4	543561·2	·9962	541515·6
128914·7	1	128914·7	1·0000	128914·7

3) 2105670·0
701890·0
⅓ Angular Interval ·0291
7018900
6317010·0
1403780·0
20425·09900
Longitudinal Interval . . . 30
Moment of Wedges uncorrected . 612752·97
Correction for appendages . . . 8839·00
" " layer . . . −2864·00
Volume of Displacement . . 86767) 418044·15
BR= . . . . . . 4·78
BG . sine 30°= . . . . 3·13
GZ=Statical Lever= . . . . 1·65

Dynamical Stability

Sines of Heel	Products for Moments
·5000	55739·7
·4226	193446·9
·3420	78756·7
·2588	124472·3
·1736	44184·3
·0871	47345·9
·0000	·0

3) 543945·8
181315·3
⅓ Angular Int ·0291
1813153
16318377
3626306
5276·27523
Long. Int 30
158288·256
1547·000
−387·000
86767) 159448·256
B_1R= . . 1·837
BG . vers 30°= ·839
Dynam. Lever=·998

APPENDAGES

Pieces	Areas	Mo. of Areas	Vols.	Mo. of Vols.
Battery	155	2495	630	14381
Stern Im.	39	130	86	275
Stern Em.	12	−12	−11	−28
Negative	−37·5	−693·7	−399	−5789
Totals	168·5	1919·3	306	8839

Moment of Statical Stability in foot tons
= 2479 × 1·65=4090
Moment of Dynamical Stability in foot tons
= 2479 × ·998=2474

sums of the functions of the cubes are multiplied by the sines of the various angles of inclination instead of the cosines; the sum of the products so obtained being divided and multiplied by the same numbers as were used for the statical stability, in order to find the moment of the wedges uncorrected relatively to the respective radial planes. The corrections for the appendages are then made, that for the correcting layer being subtracted in all cases. The moment for the correcting layer is found by multiplying its volume by half its thickness, that being about the vertical height of its centre of gravity from its radial plane. This final result divided by the total volume of displacement will give the length of the arm B′R, from which if BG . vers θ be deducted, the remainder will equal the length of the arm for the dynamical stability, or the vertical height through which the centre of gravity of the ship has been lifted and the centre of buoyancy depressed.

12. *Geometrical Mode of Calculating Dynamical Stability.*—The dynamical stability of a vessel at any given angle of heel is the sum of the moments of the statical stability taken at indefinitely small equiangular intervals up to the given angle of heel, and is therefore equal to the area of the curve of statical stability included between the origin of the curve and the angle in question. It must be noticed that the abscissæ of a curve of statical stability is given in angles, and therefore the longitudinal interval is taken in circular measure.

But, as the lengths of the arms for statical stability are generally used to construct a curve instead of the moments of stability, the area, as above found by the rule from such a curve, will necessarily give the length of the *arm* for dynamical stability and not the *moment*.

Example (see fig. 123).—To find the length of the arm for dynamical stability at an angle of 30° inclination.

Angles of Heel	Lengths of Statical Levers GZ	Simpson's Multipliers	Products
0 degrees	·0	1	·0
5 „	·2	4	·8
10 „	·42	2	·84
15 „	·68	4	2·72
20 „	·97	2	1·94
25 „	1·30	4	5·20
30 „	1·66	1	1·66
			13·16

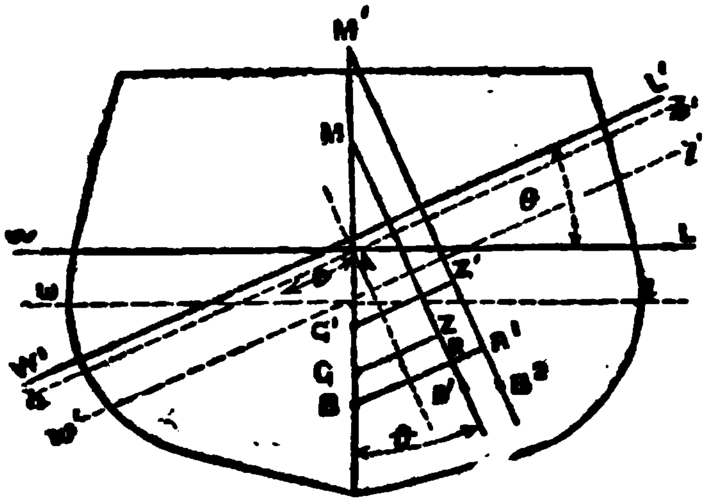
⅓ of angular interval in circular measure = ·0291

1316
11844
2632

Dynamical lever for 30° = ·382956

13. *Curve of Stability for Light Draught.*—The lengths of the arms for this curve can readily be approximated from the results obtained for the curve in the load condition.

FIG. 131.



In fig. 131 WL is the load water-line, and *wl* the light water-line, for the upright position of the vessel. If the vessel is inclined through an angle *θ*, and W′L′ is the true position of the inclined water-plane for the load condition, then the true position of the water-plane for the light condition will run parallel to it, as *w′l′*. To determine its perpendicular distance from W′L′, divide the volume of the layer contained between the light and load water-planes by the area of the assumed inclined water-plane *hh′*, which was found for the inclined load condition. Let B be the centre of buoyancy for the upright load condition, B′ for the inclined load condition, and B^2 for the inclined light condition. BR is perpendicular to the vertical B′M, and BR′ is perpendicular to the vertical B^2M'.

Let V equal volume of light displacement.
" v = volume of displacement contained between the light and load water-planes.
" c = distance of centre of gravity of assumed inclined water-plane from the vertical through A, assumed positive on the emerged side.
" GZ and G′Z′ = the lengths of the arms of the righting couples for the load and light condition respectively.

$$\text{Then } G'Z' = GZ - GG' \sin\theta + \frac{v(BR - BA\sin\theta + c)}{V}$$

Example.—In the ship illustrated in the tables (pp. 122, 123) find the lever of statical stability at 30° when light, assuming the displacement diminished by 200 tons, and the c.g. raised by 1·5 ft. B is 6·5 ft. below original upright W.L.

Here $v = 200 \times 35 = 7000$; $V = 86767 - 7000 = 79800$ approx. $GZ = 1{\cdot}65$; $GG' = 1{\cdot}5$; $\sin\theta = \frac{1}{2}$; $BR = 4{\cdot}78$; $BA = 6{\cdot}5$; $c = -1{\cdot}16$.

$$GZ' = 1{\cdot}65 - {\cdot}75 + \frac{7000(4{\cdot}78 - 3{\cdot}25 - 1{\cdot}16)}{79800} = {\cdot}93'.$$

DIRECT METHOD.

Lay a piece of tracing paper over the body plan, and on it draw a trial water-line at the correct inclination. Trace the

wedge sections, replacing the curved portions by one or two straight lines approximating as closely as possible to the curves. Find graphically the areas of the triangles and quadrilaterals, and thence determine the volume of each wedge. If these are not nearly equal raise or lower the water-line, and proceed as before until there is practical equality in volume. Find the c.g. of each triangle or quadrilateral (see p. 59) and calculate the moment of its area about any line perpendicular to the inclined water-line. Thence find the moments of the volumes and add. The total moment divided by the volume of displacement is equal to BR (fig. 119), whence GZ is at once determined.

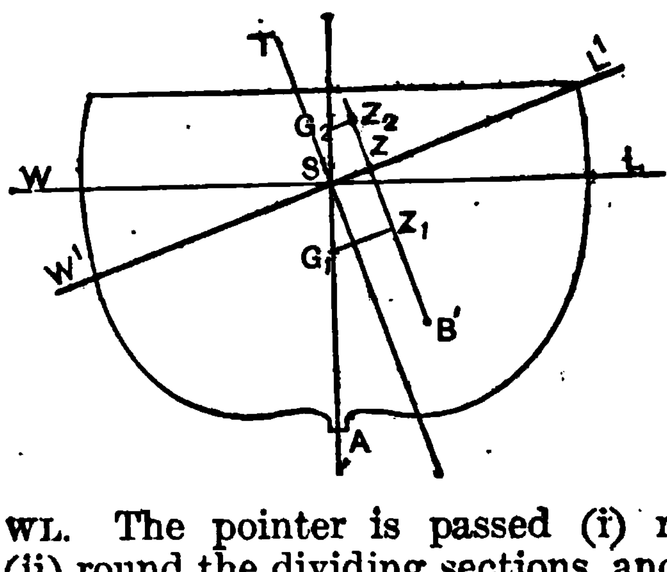
The direct method is, perhaps, the most convenient one when an integrator is not available.

AMSLER-LAFFON'S MECHANICAL INTEGRATOR.

By means of this instrument, the area, moment, and moment of inertia about any axis, can be obtained for any curvilinear area by tracing its outline with a pointer.

Its principal use is that of obtaining the stability of a vessel at various angles of heel and at various drafts. It is usual, when using this instrument, to first calculate the righting lever for a number of displacements at *one* inclination, say 15°. Then the same for 30°, 45°, and so on; the cross curves being constructed before the ordinary curves.

FIG. 132



Let fig. 132 be a body plan drawn for both sides of a ship; let WL be its upright waterline intersecting the middle line at S. Through S draw inclined waterlines at the required inclinations, and let W′L′ be any one of them, say at 15°. The first step is to find the displacement at W′L′ as it is generally different from that at WL. The pointer is passed (i) round the two end sections, (ii) round the dividing sections, and (iii) round the intermediate sections* ; the pointer in each case passing along the waterline and round the section, as W′L′AW′. Readings are taken at the start and after passing round (i), (ii), and (iii), so that after subtracting, the readings due to each of the three series of sections are known. Reading (ii) is multiplied by 2, and (iii) by 4, and the two products added to reading (i). The total is then multiplied by the common interval and the constant of the instrument and divided by 3 times the square of the scale used. The result is the volume of displacement, which is then reduced to tons.

* See Simpson's Rules.

If in the same way ST, the line through S, perpendicular to W′L′ is made the axis for moments, and the readings for moments are treated in the same way as those for areas, it is evident that the final result will be the moment of the underwater portion about ST as axis (obviously, the total must now be divided by 3 times the *cube* of the scale instead of the square). This divided by the volume of displacement will give the perpendicular distance of the inclined centre of buoyancy from ST; that is SZ, when B′Z is parallel to ST.

The righting lever, or GZ, is equal to SZ + SG sin θ when G is below S as at G_1; and equal to SZ − SG sin θ when G is above S.

The righting lever GZ is set off at its proper displacement on the cross curve for 15°. This is done at different waterlines and the cross curve thus completed.

The following is the actual form of the calculation for SZ.

Sections 10·6 apart. Scale of body $\frac{1}{4}''$ to 1 foot.

$$\text{Machine constants} \begin{cases} \text{Areas} & \dfrac{20}{1000}. \\ \text{Moments} & \dfrac{40}{1000}. \end{cases}$$

Angle of Heel 15°								
	Areas				Moments			
Sections	Readings	Differences	Simpson's Multipliers	Products	Readings	Differences	Simpson's Multipliers	Products
Initial . .	4029	—	—	—	982	—	—	—
End ordinates. .	4111	82	1	82	986	4	1	4
Dividing ordinat.	10502	6391	2	12782	1398	412	2	824
Intermediate „ .	17309	6807	4	27228	1819	421	4	1684
				40092				2512

Displacement in tons

$$= 40092 \times \frac{20}{1000} \times (4)^2 \times \frac{10{\cdot}5}{3} \times \frac{1}{35} = 1283.$$

$$\text{SZ} = \frac{2512}{40092} \times \frac{40}{20} \times 4 = {\cdot}5 \text{ feet.*}$$

* The 4 multiplier is the reciprocal of the scale of the drawing.

Tchebycheff's rule (see p. 43) can be very usefully employed instead of Simpson's rule in the above; the saving of time due to its adoption is, for a complete set of cross curves, more than sufficient to compensate for the time of preparing the special body plan, which need only be drawn in fairly roughly. In this labour may be avoided by using the sections numbered 2, 5, 7, 10, 12, 15, 17, and 20 from an ordinary body plan whose equidistant sections are numbered 1 to 21. It will be found that these coincide nearly in position with those required with Tchebycheff's rule for 4 ordinates, repeated. This was pointed out at Inst. N.A., 1915, by Mr. W. J. Luke.

Example.—Length of ship, 210 feet; number of sections, 8; scale of body, $\frac{1}{4}''$ to 1 foot. Machine constants as before.

$$\text{Displacement in tons} = \frac{20}{1000} \times 16 \times \frac{210}{8} \times \frac{1}{35} \times \text{area reading.}$$

$$\text{SZ} = \frac{\text{Moment reading}}{\text{Area reading}} \times 8$$

4 = the scale
2 = ratio of machine constants.

Note.—The above or 'all-round' method is the simplest, since it gives directly the stability lever desired. A more accurate and expeditious method, however, is that known as the 'figure-eight'. The pointer is passed around the outline of the wedge sections, only, taking them in the opposite directions on the two sides of the ship; e.g. commencing at S (fig. 132) the pointer reaches the points L′, L, S, W, W′, S in the order named. The result is to give the difference of the wedge volumes (by the area reading) and the sum of their moments (by the moment reading). If V be the original volume of displacement, v the increased volume registered by the machine, and M the moment registered (the last two being found from the readings as in the 'all-round' method), and BS the distance of the upright C.B. below S,

$$\text{SZ} = \frac{\text{M} - \text{V} \cdot \text{BS} \sin\theta}{\text{V} + v}.$$

Formulæ for Stability Levers in Special Cases.

1. *Ship with concentric circular sections, cylinder.*—The metacentric method is here applicable to all angles of heel and statical lever $\text{GZ} = \text{GM} \sin\theta$, dynamical lever $= \text{GM} \operatorname{vers}\theta$.

2. *Wholly immersed vessel.*—The metacentre and centre of buoyancy are coincident, and the above formulæ apply if B be substituted for M.

3. *Wall-sided vessel, parabolic cylinder.*—Statical lever $\text{GZ} = \sin\theta\,(\text{GM} + \frac{1}{2}\,\text{BM} \tan^2\theta)$.

Dynamical lever $= \text{GM}\,(1 - \cos\theta) + \frac{1}{2}\,\text{BM}\,(\sec\theta + \cos\theta - 2)$.

For BM, its value when ship is upright is intended.

CHANGE OF METACENTRIC HEIGHT DUE TO SMALL CHANGES IN DIMENSIONS.

Let the beam of a ship be increased by $\frac{1}{n_1}$ of itself, all transverse ordinates being augmented in the same proportion. Similarly let the draught be increased by $\frac{1}{n_2}$ of itself. If these changes are moderate, and the height of the c.g. above the keel be assumed to vary as the draught, the increase of metacentric height is given by—

$$\frac{\delta m}{m} = \frac{2}{n_1}\left(1 + \frac{a}{m}\right) - \frac{1}{n_2}\left(1 + \frac{2a}{m}\right) \quad . \quad . \quad . \quad (1)$$

where m is the original GM, δm the increase of GM, and a is BG.

If the beam only be increased, $\frac{1}{n_2} = 0$, and

$$\frac{\delta m}{m} = \frac{2}{n_1}\left(1 + \frac{a}{m}\right) \quad . \quad . \quad . \quad (2)$$

If the draught be diminished so as to maintain the same displacement as before, $\frac{1}{n_2} = -\frac{1}{n_1}$, and

$$\frac{\delta m}{m} = \frac{1}{n}\left(3 + \frac{4a}{m}\right) \quad . \quad . \quad . \quad (3)$$

In the preceding case if the total depth be unaltered (the freeboard being increased to compensate for the diminution of draught), and if μ represent the height of the c.g. above the keel, originally,

$$\frac{\delta m}{m} = \frac{1}{n}\left(3 + \frac{4a - \mu}{m}\right) \quad . \quad . \quad . \quad (4)$$

If in the preceding case it be assumed alternatively that the freeboard is unaltered (the height of c.g. above keel varying as the total depth as before), and if s represent the original ratio — freeboard ÷ draught,

$$\frac{\delta m}{m} = \frac{1}{n}\left\{3 + \frac{1}{m}\left(4a - \frac{\mu s}{1+s}\right)\right\} \quad . \quad . \quad . \quad (5)$$

In the general case, determine the effect on GM of increasing the beam by one foot, assuming that BM $\propto$ LB$^3/\Delta$. The increase of GM roughly varies as that of beam.

Example 1.—In making a preliminary estimate of the dimensions of a new design, the beam is assumed 36 feet, the distance BG is 8 feet and GM is 1 foot. It is desired to double the metacentric height, while maintaining the draught unaltered. Find the beam required.

Using formula (2), $\delta m = 1$, $m = 1$, $a = 8$.

Whence $\frac{2}{n_1}(1 + 8) = 1$, or $\frac{1}{n} = \frac{1}{18}$.

Therefore the beam required is 36 $(1 + \frac{1}{18})$ or 38 feet.

Note that if it is desired not to alter the displacement, the ength must be diminished by $\frac{1}{18}$ of itself.

Example 2.—In a battleship having beam 89 feet, mean draught 27 feet, GM 5 feet, G above water-line $6\frac{1}{2}$ feet, and BG 18 feet, find the effect on the metacentric height of increasing the beam by 1 foot, assuming that owing to a change in the distribution of weights the c.g. is 0·35 feet higher above the water-line in the new design. The displacement and length are assumed unaltered.

Using formula (3), $m = 5$, $n_1 = \frac{1}{89}$, $a = 18$.

Whence $\frac{\delta m}{5} = \frac{1}{89}\left(8 + \frac{72}{5}\right) = \cdot 195$ or $\delta m = \cdot 98$ feet.

But this assumes that the height of G above water-line becomes $6\cdot 5\left(1 + \frac{1}{n_2}\right)$ or $6\cdot 5\left(1 - \frac{1}{89}\right)$ or 6·43 feet; it is actually 6·85 feet.

Hence the metacentric height is $5 + \cdot 98 - (6\cdot 85 - 6\cdot 43) = 5\cdot 56$ feet.

Alteration of Stability Curve due to Small Changes in Dimensions.

Assume the beam increased by $\frac{1}{n_1}$ of itself, and the draught by $\frac{1}{n_2}$ of itself as above. This process is applicable to any two ships of fairly similar form, even if they depart somewhat from exact proportionality. Given the curve of statical stability (GZ) for the first ship, it is required to construct the corresponding curve for the desired vessel without constructing the body plan or performing the usual calculations.

Rule.—1. Construct the curve of dynamical stability of the first ship by taking areas of the GZ curve (see p. 116). Two or three spots are sufficient, as great accuracy is not required.

2. Corresponding to the angle θ at which the stability lever is required in the new ship, determine an angle ϕ from the formula—

$$\left(1 + \frac{1}{n_2}\right)\tan\phi = \left(1 + \frac{1}{n_1}\right)\tan\theta.$$

3. Determine GZ, the statical lever, and z the dynamical stability lever for the original ship at the angle ϕ.

4. Determine δm, the increase of metacentric height, by the methods of the previous page.

5. Then the stability lever G′Z′ of the new ship at the angle θ is given by—

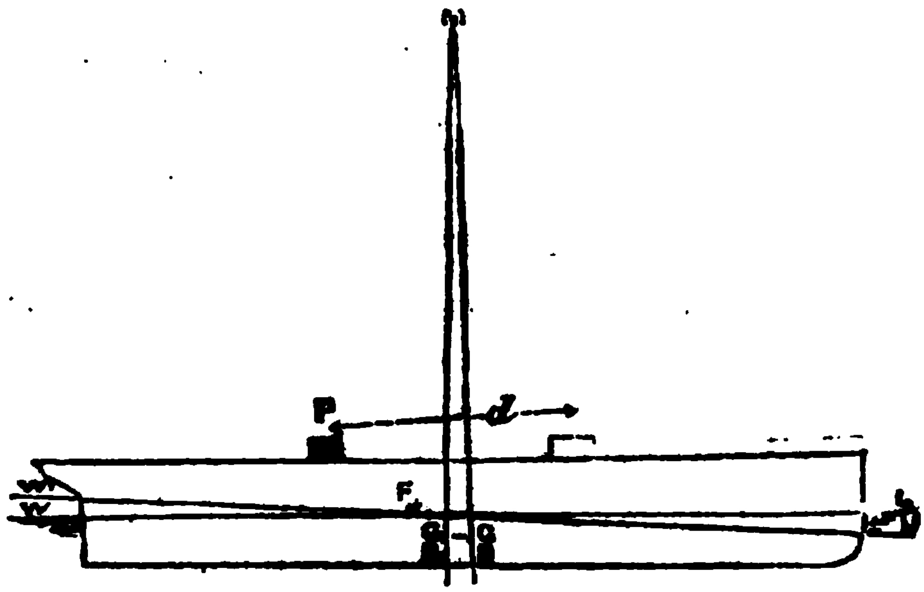
$$\begin{aligned} \mathrm{G'Z'} - \mathrm{GZ} &= \delta m \sin\theta + \tfrac{1}{2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)(\mathrm{GZ} - m\sin\phi) \\ &\quad + \tfrac{1}{2}\left(\frac{1}{n_1} - \frac{1}{n_2}\right)(\mathrm{GZ}\cos 2\phi + 2\sin 2\phi\,(a + z) - (3m + 4a)\sin\phi). \end{aligned}$$

By calculating $G'Z'$ for about 3 values of θ, the stability curve can be described by the aid of the tangent at the origin as given by the GM.

LONGITUDINAL STABILITY.

Definitions.—1. The *centre of flotation* is the centre of gravity of the water-plane; it is denoted by F in fig. 133. For longitudinal inclinations without change of displacement the water-planes intersect on a transverse axis passing through the centre of flotation.

FIG. 133.



2. The difference between the draught forward and that aft is termed the *trim*. If the former is greater the trim is by the bow, and vice-versa. When not stated the draughts are supposed taken at the perpendiculars; they are actually measured at the draught marks which are frequently placed at the extremities of the straight keel.

3. *Change of trim* is the sum of the changes of draught forward and aft if one is increased and the other diminished; otherwise it is the difference between the changes of draught.

To determine the draughts and trim at the draught marks given those at the perpendicular, and the converse.

Let L = length of ship between perpendiculars.
a, b = distance of forward and after draught marks from amidships.
D_1, D_2 = draughts at F.P. and A.P.
D_3, D_4 = draughts at forward and after draught marks.

$$D_3 = \frac{D_1 + D_2}{2} + \frac{a}{L}(D_1 - D_2).$$

$$D_4 = \frac{D_1 + D_2}{2} + \frac{b}{L}(D_2 - D_1).$$

$$D_4 - D_3 = \frac{a+b}{L}(D_2 - D_1).$$

$$(a+b)D_1 = D_3\left(\frac{L}{2}+b\right) - D_4\left(\frac{L}{2}-a\right)$$

$$(a+b)D_2 = D_4\left(\frac{L}{2}+a\right) - D_3\left(\frac{L}{2}-b\right)$$

To determine the displacement of a vessel floating out of her designed trim.

Let D be mean draught amidships, W the corresponding displacement as obtained from the displacement sheet, T the tons per inch, d the number of inches excess of trim by the stern, L the length in feet between perpendiculars, and c the distance of the centre of flotation abaft amidships in feet.

Then virtual mean draught is $D + \dfrac{cd''}{L}$

Hence the displacement is $\quad W + \dfrac{Tcd}{L}$ tons.

Ex.—In a ship where $L = 400$, $c = 15$, $T = 80$, the displacement deduced from the mean draught is 14,000 tons where the ship has a trim of 2 feet from the bow. If the normal trim be 1 foot by the stern, find the true displacement.

Here $d = -36''$, and increase of displacement is

$$-\frac{80 \times 15 \times 36}{400} = -108 \text{ tons.}$$

Hence displacement is $14{,}000 - 108 = 13{,}892$ tons.

Note.—1. The distance c expressed as a fraction of the ship's length has the following average values :—Battleship $\frac{1}{18}$, light cruiser $\frac{1}{22}$, T.B. destroyer $\frac{1}{25}$, steam yacht $\frac{1}{30}$, channel steamer, $\frac{1}{30}$, cargo steamer $\frac{1}{100}$.

2. The centres of buoyancy and gravity lie abaft the midship section at a distance, which, expressed as a fraction of the ship's length, has the following average values :—Battleship $\frac{1}{25}$, light cruiser $\frac{1}{55}$, T.B. destroyer $\frac{1}{90}$, steam yacht $\frac{1}{70}$, channel steamer $\frac{1}{50}$, cargo steamer 0.

3. For a change of trim t without change of displacement, the draught forward is altered by $\dfrac{t}{2} + \dfrac{tc}{L}$ and that aft by $\dfrac{t}{2} - \dfrac{tc}{L}$

To find the changes of draught and trim in passing from salt to fresh water, and vice versa.

Let the symbols W, T, and D above refer to salt water. Let δ inches be the sinkage in fresh water, and D′ the final mean draught.

Then $D' = D + \delta/12$; $\delta = \dfrac{\cdot 9W}{35T} = \dfrac{W}{38 \cdot 9T}$

It is assumed above that the fresh water occupies 35·9 cubic

feet to the ton. If the water is brackish, and occupies $35+x$ cubic feet to the ton, the latter formula becomes

$$\delta = \frac{x\text{W}}{35\text{T}}$$

The change of trim is usually very small. If c' be the distance of the centre of flotation abaft the centre of buoyancy, and M the moment to change trim in salt water, the change of trim by the bow on passing from salt to brackish water is, in inches, $\frac{x c' \text{W}}{35 \text{M}}$; or $\frac{c'\text{W}}{38 \cdot 9\text{M}}$ for fresh water where x is $\cdot 9$.

Ex.—Find the changes of draught and trim in a light cruiser on passing into fresh water if $\text{W} = 3000$, $\text{T} = 25$, $\text{M} = 650$, $c' = 11$.

$$\text{Increase of mean draught} = \frac{3000}{38 \cdot 9 \times 25} = 3 \cdot 1 \text{ inches.}$$

$$\text{Change of trim by the bow} = \frac{11 \times 3000}{38 \cdot 9 \times 650} = 1 \cdot 3 \text{ inches.}$$

To determine the positions at which a weight must be added or removed so as to leave the draught at one end constant.

RULE.—To maintain constant draught at a distance y abaft (*or before*) the centre of flotation, place the weight at a distance x before (*or abaft*) the centre of flotation, where $x = \frac{\text{ML}}{\text{T}y}$. If constant draught is desired at either perpendicular, the two points for the weight are situated at a distance $\frac{2\text{M}}{\text{T}}$ very nearly from the C.F. This distance is about $\frac{60\text{T}}{\text{B}}$, or about $\frac{\text{L}}{10}$ in many ships.

To determine the vertical height of the longitudinal metacentre above the centre of buoyancy.

Divide the moment of inertia of the water-plane relatively to a transverse axis passing through the centre of flotation by the volume of displacement (for example, see displacement sheet and explanation on pp. 94, 99).

Note.—This height is frequently greater than the ship's length, so that BG is negligible in comparison; then GM = BM approximately.

Moment to alter trim of a vessel.—In fig. 133 let the weight P be moved forward through a longitudinal distance d, changing the water-line from WL to W′L′.

Then $\text{P}d = \text{W}.\text{GG}_1 = \frac{\text{W}.\text{GM}}{\theta} = \frac{\text{W} \times \text{GM} \times \text{trim in feet}}{\text{L}}$; hence trim in inches $= \frac{12\,\text{P}d\,\text{L}}{\text{W} \times \text{GM}}$

The product Pd is the moment causing trim; if several weights are moved, their moments are added, allowing for sign. Note that the *moment to change trim one inch* is equal to the expression $\frac{W \times GM}{12L}$. This is fairly constant within moderate changes of draught, and practically unaffected by vertical shifts of weight.

Approximate formulæ.

1. (J. A. Normand). Long. $BM = 13{,}000 \frac{T^2L}{BV}$, L = length on L.W.L in feet, B = beam in feet, V = volume of displacement in cubic feet, T = tons per inch.

2. (Derived from the preceding)

$$\text{Moment to change trim } 1'' = 30 \frac{T^2}{B}$$

3. Moment to change trim $1'' = L^2B/10{,}000$ in ships of ordinary form, $TL \div 18 \cdot 5$.

Effect of Adding Weights of Moderate Amount.

The weights added are supposed insufficient to affect appreciably the transverse stability, or to cause relatively large heel, trim, or immersion.

Rule.—Find the distance of each weight from the middle line plane and from amidships. Calculate the moments, positive and negative (weights removed are considered negative), and add

$$\text{Mean sinkage} = \text{weight added} \div \text{tons per inch.}$$

$$\text{Heel in degrees} = 57 \cdot 3 \times \frac{\text{transverse moment}}{\text{displacement} \times GM}$$

$$\text{Trim in inches} = \frac{\text{longitudinal moment about centre of flotation}}{\text{moment to change trim 1 inch.}}$$

$$= \frac{\text{longitudinal moment about } \otimes \pm (w \times \text{C.F. abaft } \otimes)}{\text{moment to change trim 1 inch}}$$

using + sign when the net weight (w) added or subtracted is before amidships.

Effect of Adding Weights of Considerable Amount.

Rule.—Add the weights and their moments as above, including in addition the vertical moments required to find the rise or fall of the c.g.

The new mean draught is found from the curve of displacement, or more accurately from the curve of tons per inch, by estimating the mean tons per inch between the two waterlines. If necessary make the correction due to the position of the centre of flotation as described on p. 132.

To obtain the heel find first the vertical position of G; from the metacentric diagram the new GM is obtained. The lateral

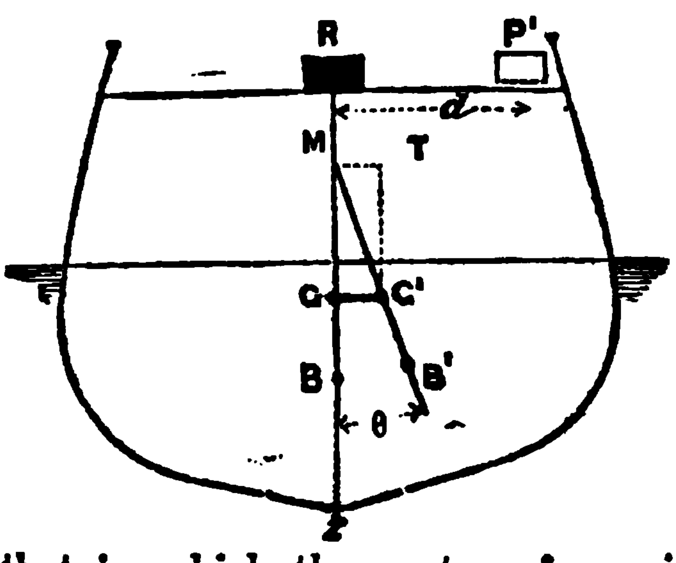
movement (GG′) of G is found by dividing the transverse moment by the new displacement. A moderate angle (θ) of heel is given by the formula $\tan\theta = GG'/GM$. If θ is very large, construct a curve of stability for the new condition, using the cross curves, and find by trial the angle θ at which the relation $GG' = GZ \sec\theta$ holds.

For the trim the method given on the preceding page is usually sufficiently accurate. If, however, the sinkage is very great, construct a curve of moment to change trim 1 inch on a base of draught, also one giving the longitudinal position of the centre of buoyancy. Then at the original displacement if the trim be by the stem, the distance of G abaft B is equal to the trim in inches × moment to change trim 1 inch at that draught (found from the curve) ÷ displacement. Knowing the longitudinal position of B from the curve, that of G is obtained. The change in this due to the added weights is then determined; and the above process, reversed and using the final moment, positions of B and G, and displacement, gives the final trim.

Examples of the above methods are given in the inclining experiment described below.

To Determine the Vertical Position of a Ship's Centre of Gravity by Experiment.

Fig. 134.



In fig. 134 let MZ be the upright axis of a ship; her centre of gravity then lies somewhere in that axis. M is the metacentre, and GM its vertical height above the centre of gravity G.

If a weight P be moved transversely through a distance $PP' = d$, it will heel the vessel over through an angle θ, and her centre of gravity will then shift in a direction GG′ parallel to that in which the centre of gravity of the weight has been shifted. Let MT be parallel to GG′ and TG′ parallel to GM; let P = weight shifted in tons, and W = displacement of ship in tons: then

$$MT = GG' = \frac{P \times d}{W}, \text{ and } GM = GG' \cot\theta = \frac{P \times d}{W}\cot\theta.$$

In practice the ballast is usually in the form of pig iron arranged in two parallel rows on the port and starboard sides of the upper deck.

The method of performing the experiment is illustrated by the calculations below, which correspond to a light cruiser, whose metacentric diagram is given in fig. 121.

Density of water, 35·1 cubic feet per ton. Length of ship, 385 feet. Ballast, 30 ton[s]
Shift, 28 ft. 6 in. Pendulums, 15 feet long, two in number.

Readings	7½ tons ballast, S. to P. .	For'd $4\frac{3}{16}''$	Aft $4\frac{3}{16}''$	Measurements ma[de] from initial zero
	15 " " " .	" $8\frac{1}{4}''$	" $8\frac{5}{16}''$	
	Ballast replaced .	" $\frac{3}{16}''$ S.	" $\frac{3}{16}''$ S.	
	7½ tons ballast, P. to S. .	" $4''$	" $4''$	
	15 " " " .	" $8\frac{3}{16}''$	" $8\frac{3}{16}''$	

Draught at marks (40′ abaft F.P.; 50′ before A.P.)	For'd .	Port	10′ 11″	Starboard	10′ 11″
	Aft .	"	13′ 7½″	"	13′ 7″

Deep Condition; Weights to go on Board.

Item.	Weight of Item.	About 11 Ordinates. Before.	Moment.	Abaft.	Moment.	About L.W.L. Above.	Moment.	Below.	Moment.
Fresh water	27	82	2214	—	—	—	—	7·5	[illegible]02·5
Fresh water in filters	1	—	—	27	27	6·1	6·1	—	—
Boats	14·8	—	—	21	310·8	19·7	291·56	—	—
Officers, crew	38·0	—	—	23	874·0	5·0	190·0	—	—
Water in gravity tank	1·0	—	—	4	4·0	21·5	21·5	—	—
Provisions	28·0	15	420	—	—	—	—	5	140·[illegible]
Officers' stores and slops	25·0	105	2625	—	—	—	—	3	75·[illegible]
Wireless	3·5	—	—	40	140	94	329·0	—	—
Paint	11·0	—	—	—	—	—	—	—	—
Sails and awnings	3·2	—	—	13·3	42·56	22	70·4	—	—
Rigging and blocks	4·25	—	—	8·0	34	64	272·0	—	—
Powder and cases	11·94	24	286·56	—	—	—	—	8	95·[illegible]
Saluting ammunition	·1	128	12·8	—	—	—	—	7	·7
Shot and shell	20·76	42·5	882·3	—	—	—	—	7·5	155·7
Practice shot	1·16	46·0	53·36	—	—	—	—	10	11·6
Small arms & ammunition	1·45	128·0	185·6	—	—	—	—	6·5	9·4
Torpedo heads	1·1	84·0	92·4	—	—	—	—	10	11·0
Torpedo bodies	3·2	—	—	2·0	64·0	6·5	20·8	—	—
Maxim ammunition	·45	128	57·6	—	—	—	—	6·5	2·[illegible]
Reserve feed	92·0	·3	27·6	—	—	—	—	11·5	1058·[illegible]
Coal to fill upper bunkers	577·3	1·7	981·41	—	—	6·2	3579·26	—	—
Coal to fill lower bunkers	147·7	14·9	2200·73	—	—	—	—	3·7	546·[illegible]
Oil fuel	142·2	—	—	18·5	2630·7	—	—	11·4	1621·[illegible]
Water in boilers	41·2	26·3	1083·56	—	—	—	—	4·2	173·[illegible]
Water in condensers, pipes, pumps, etc.	16·5	—	—	64·5	1064·25	—	—	3·35	55·[illegible]
Feed tanks (half full)	5·5	—	—	5·8	319·0	—	—	5·0	27·[illegible]
Engineers' stores	7·1	—	—	118	837·8	—	—	4·0	28·[illegible]
Water in evaporators and distillers	1·5	—	—	77	115·5	—	—	3·1	4·[illegible]
Mess tables	3·0	—	—	118·5	355·5	4	12	—	—
General fittings	1·0	12	12	—	—	10	10	—	—
Water in sanitary tank	4·0	—	—	45·1	180·4	17·3	69·2	—	—
Total	1235·91	—	11134·92	—	6999·51	—	4871·82	—	4218·[illegible]
To come out.									
Ballast	30·0	—	—	30·3	909·0	10·8	324	—	—
Lumber	6	—	—	7·3	43·8	8·4	50·4	—	—
Men	5	—	—	32·0	160·0	14·0	70·4	—	—
Oil fuel	1·9	—	—	1·0	1·9	—	—	10·2	19·[illegible]
Total	42·9	—	—	—	1114·7	—	444·4	—	19·[illegible]
To be shifted.									
Engineers' stores	—	—	—	—	—	—	—	—	8·[illegible]
Boatswain's stores	—	—	—	—	161	—	3	—	—
Machinery	—	—	536	—	—	—	—	—	8
Total	—	—	536	—	161	—	3	—	16·[illegible]
Summary.									
To go on	1235·9	—	11134·92	—	6999·51	—	4871·82	—	4218·[illegible]
To come off	−42·9	—	+1114·7	—	—	—	+19·38	—	+444·[illegible]
To shift	—	—	536·0	—	161·0	—	3·0	—	16·[illegible]
To add, net	1193·0	4·72′	12785·62	—	7160·51	—	4894·20	—	4679·[illegible]
			7160·51				4679·71		
			5625·11				214·49		

C. flotation abaft ⚹ = 16 ft. Trim assumed in metacentric diagram = 1 foot.

Assume moment to change trim 1 inch as 585 ft.-tons at all draughts.

Mean reading for 15-ton shift =

$$\tfrac{1}{8}\{2(4\tfrac{3}{16} + 4\tfrac{3}{16} + 4 + 4) + (8\tfrac{1}{4} + 8\tfrac{5}{16} + 8\tfrac{3}{16} + 8\tfrac{3}{16})\} = 8\cdot21 \text{ in.}$$

Draughts at perpendiculars (see p. 131) are 10 ft. $6\frac{1}{2}$ in. for'd and 14 ft. $0\frac{1}{2}$ in. aft; giving 12 ft. $3\frac{1}{2}$ in. mean draught, and 42 in. trim between perpendiculars, i.e. 30 in. excess trim.

Correction for C.F. (see p. 132) is $\dfrac{30}{385} \times 16 \times 26\cdot4 = 33$ tons.

Hence displacement when inclined =

2914 (from displacement curve) + 33 = 2947 tons.

$$\text{Hence GM} = \frac{Pd}{W}\cot\theta = \frac{15 \times 28\cdot5}{2947} \times \frac{15 \times 12}{8\cdot21} = 3\cdot18 \text{ ft.}$$

M above L.W.L. as calculated (see note 5 below) = $4\cdot28$ ft.

∴ G above L.W.L. = $1\cdot1$ ft.

For deep condition add 1193 tons. G $4\cdot72$ ft. abaft, ⚹ having a moment of 214 ft.-tons above L.W.L.

Hence in deep condition displacement = 1193 + 2947 = 4140 tons.

$$\text{G above L.W.L.} = \frac{214 + (2947 \times 1\cdot1)}{4140} = \cdot78 \text{ ft.}$$

M above L.W.L. = $3\cdot61$ ft. (from metacentric diagram),

∴ GM in deep condition = $3\cdot61 - \cdot75 = 2\cdot83$ ft.

G of weight added before centre of flotation = $16 - 4\cdot7 = 11\cdot3$ ft.

$$\text{Change of trim by bow} = \frac{1193 \times 11\cdot3}{585} = 23 \text{ in.}$$

∴ Final trim by stern = 42 − 23 = 19 in. Mean draught (from diagram) = 16 ft. $0\frac{1}{2}$ in.

$$\text{Draught F.P.} = 16 \text{ ft. } 0\tfrac{1}{2} \text{ in.} - 6 - 7 \times \frac{16 + 192\cdot5}{385} = 15 \text{ ft. } 2\tfrac{3}{4} \text{ in.}$$

$$\text{Draught A.P.} = 16 \text{ ft. } 0\tfrac{1}{2} \text{ in.} + 6 + 7 \times \frac{192\cdot5 - 16}{385} = 16 \text{ ft. } 9\tfrac{3}{4} \text{ in.}$$

The normal and light conditions are dealt with similarly.

Note.—1. The experiment should be performed in calm weather, ship being moored head and stern, or allowed to drift, so as to eliminate as far as possible the effect of all external influences on the result.

2. An account of all weights on board should be previously made. No moveable weights such as loose water or oil should be allowed; men on board should remain in definite positions when the readings are taken.

3. The readings are taken along horizontal battens, so as to be directly proportional to tan θ. The pendulum bobs can be allowed to hang in water, if necessary, to render them steady. If there be difficulty in obtaining a really steady reading, wait until the oscillations are diminishing fairly

regularly, and then note the reading at the ends of three consecutive oscillations. The mean can then be taken as the sum of one-quarter of the first and third readings and one-half the second. About 3 degrees is usually a suitable angle of heel. The quantity of ballast required should be estimated beforehand from the probable GM; usually from $\frac{1}{2}$ (large ships) to 1 per cent (small ships) of the displacement is sufficient.

4. The readings taken in the middle of the experiment are for checking purposes only, and, if small, should be ignored; all readings being taken from the original zero. If the check readings are large the cause of the discrepancy should be investigated and removed, and the first readings repeated.

5. If the vessel be greatly out of trim when inclined, greater accuracy is obtained if the positions of B and M be re-calculated in lieu of taking their positions as given in the metacentric diagram. The distance BM is readily found from the ordinates of the inclined water-plane; if the trim be by the stern BM is generally increased. The height of B can be found exactly by taking a wedge of buoyancy between the water-line and one of the original water-lines, treating this as an appendage; but, for an approximation, the rise of B above its position at the same displacement on the metacentric diagram is equal to $\frac{1}{2}\text{BM}_L \frac{T^2}{L^2}$ where BM_L is the longitudinal BM and T the trim in feet.

6. The draughts should be read as accurately as possible before the experiment, and checked afterwards. If there is a slight "lop" in the water, a glass tube 3 feet or more in length and $\frac{1}{2}$ inch or more in diameter, if held against the side of the vessel, will give a water-level whose height can be accurately measured.

7. The method of allowing for the added weights is described on p. 134. If great accuracy be desired in the estimation of the trim (supposed large), it is preferable to adopt the second method, and calculate the longitudinal position of G, using curves of moment to change trim 1 inch and of longitudinal position of B. Note that G lies abaft B by BG sin θ, where θ is the angle of trim.

Buoyancy and Stability as affected by admitting Water into Watertight Compartments.

The compartments are supposed to be empty, unless otherwise stated. The volume of frames, plating, etc., is neglected.

1st case.

Water admitted into one or several compartments bounded by a flat so that they are entirely filled.

Treat as added weight, using the methods of pp. 134 *ff*. If the amount admitted is large and so placed as to immerse partly the upper deck or in any way to change greatly the

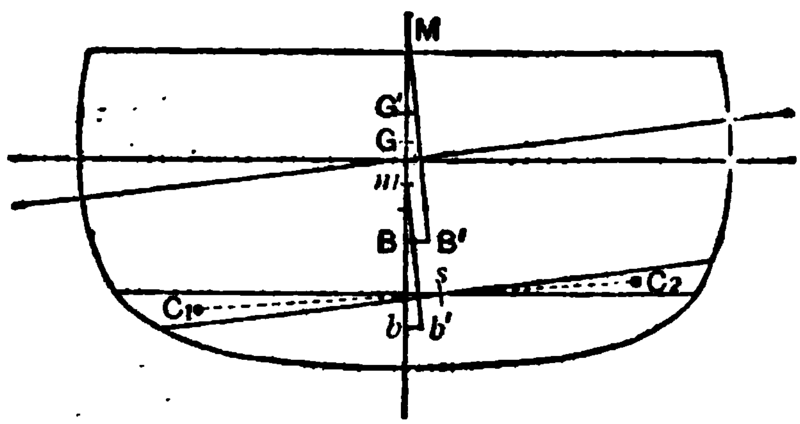
stability, a process of trial and error must be used. This should be continued until the line joining B and G is vertical, i.e. perpendicular to the assumed inclined water-plane.

2nd case. (Fig. 135.)

Water admitted into a central watertight compartment, which is not entirely filled.

Let M (fig. 135) = metacentre with free water on board.
θ = angle of inclination.
B and B′ = centres of buoyancy when upright and inclined respectively.
b and b' = centres of gravity of free water when upright and inclined respectively.
G = centre of gravity of ship and free water when upright.
S = intersection of upright and inclined free-water surfaces.
W = weight of ship and free water in tons.
V = volume of displacement in cubic feet.
v = volume of free water only in cubic feet.
i = moment of inertia of free water-surface about fore and aft axis through S.

FIG. 135.



The ship, as she inclines through the angle θ, has the centre of buoyancy B carried to B′, and the centre of gravity of the free water carried from b to b'. If C_1 and C_2 be the centres of gravity of the wedges of emersion and immersion respectively of the free water, and v_θ be the volume of either wedge, then

$$C_1C_2 \times v_\theta = bb' \times V.$$

It is evident that $C_1C_2 \times v_\theta = i \times \sin\theta$.

Then $bb' \times V = i \times \sin\theta$, or $bm = \dfrac{bb'}{\sin\theta} = \dfrac{i}{V}$, where m is the intersection of the verticals through b and b'.

Then for any small angle of inclination, the water in the ship will shift round until its centre of gravity is in a vertical line with m, so that for heeling purposes its centre of gravity may be considered to be at m instead of b.

This will raise G, the centre of gravity of the ship and water, to G′, so that $GG' \times W = bm \times 35 \times v$.

$$\text{Then} \quad GG' = \frac{bm \times 35v}{W} = \frac{bm \times v}{V} = \frac{i}{v} \times \frac{v}{V} = \frac{i}{V}$$

So that the loss of metacentric height, due to the mobility of the water, is equal to the moment of inertia of its free surface, about the middle line, divided by the total volume of displacement.

The moment of stability for a small angle θ.

$$= W \times G'M \times \sin\theta = W \times (GM - GG') \times \sin\theta = W \times \left(GM - \frac{i}{V}\right) \sin\theta.$$

Note.—1. It is immaterial whether the level inside be or be not the same as that outside. If the free water-surface be divided by longitudinal bulkheads which entirely prevent communication between adjacent compartments, find the moment of inertia of each portion about a longitudinal axis through the centre of gravity of the free surface of that portion, and add them to obtain 'i'. If, however, any compartment be in communication with the sea, its moment of inertia should be taken about the centre line of ship. At larger angles of heel, the shift of b can be estimated by methods, e.g. with the integrator, similar to that used for the shift of B in estimating the intact stability. Oil or ballast tanks are generally assumed half full.

2. Allowance should be made also for the weight of water added, regarded as solid. Since the loss of stability due to mobility depends only on its free surface, and the gain of stability depends on the weight and position of the water added, there is usually a net loss of initial stability for small depths of water and a net gain for large depths.

3. If oil or other fluid whose density is σ times that of the water be used, the virtual rise of G is $\frac{\sigma i}{V}$. For oil fuel as compared with salt water $\sigma = \cdot 91$.

4. If the compartments are not entirely empty, both the weight of water admitted and the loss of GM (i/V) are reduced in a certain proportion. In bunkers or spaces filled with coal, three-eighths of the space is void. For example, if 800 tons of water were admitted with a consequent loss of 0·8 feet of GM with empty bunkers, these figures would respectively become 300 tons and 0·3 feet if bunkers were fully stowed.

3rd case.

Water admitted into a non-central compartment which is not entirely filled.

If the damage is very large, use a process of trial and error as in the first case; allowance must here be made for the adjustment of the water-plane as the vessel trims and

heels. For moderate damage, where metacentric methods are available, proceed as follows :—

1. Find the mean sinkage by dividing the volume of water admitted up to the original water-level by the area of the *intact* water-plane.

2. Assuming first that the water-line rises parallel to itself by the above amount, find the new displacement and height of G, including the water thus added.

3. Find the position of the intact centre of flotation by deducting the moments of the areas bilged.

4. Find the intact moments of inertia about longitudinal and transverse axes through the intact C.F.; thence determine the new transverse and longitudinal stabilities in conjunction with the new G and B.

5. Using these new data, calculate the heel and trim due to the water assumed added in (2) above.

Example.—A rectangular pontoon 300′ × 12′ × 4′ draught is divided by a longitudinal bulkhead at the middle line, and by four transverse bulkheads equidistantly spaced. An end compartment is bilged on one side. Find the heel and draughts, if the metacentric height is originally 2 feet.

$$\text{Original BM} = B^2/12D = \frac{12 \times 12}{12 \times 4} = 3'.$$

B above keel = 2′. Hence G above keel = 3 + 2 − 2 = 3′.

Volume of water added to original waterline = 60 × 6 × 4 = 1440 cubic feet (G 2′ above keel).

$$\text{Mean sinkage} = \frac{1440}{(300 \times 12) - (60 \times 6)} = \frac{4'}{9}$$

Total volume of displacement = 14400 + 1440 = 15840 cubic ft.

$$\text{New height of G above keel} = \frac{(14400 \times 3) + (1440 \times 2)}{15840} = 2{\cdot}91'.$$

New height of B above keel = 2·22′ (approx.). Hence BG = ·69′.

Calculation for C.F. and M.I.

(*a*) transverse.

Item.	Area.	G from centre.	Mmt.	M.I. about centre.	
Original water-plane	3600	—	—	$\frac{1}{12} \times 300 \times 12^3$ =	43200
Portion lost . . .	360	3	1080	$\frac{1}{3} \times 60 \times 6^3$ =	4320
Intact water-plane .	3240	$\frac{1}{3}$	1080		38880
				$3240 \times (\frac{1}{3})^2$ =	360
				M.I. about axis through new C.F. =	38520

(*b*) longitudinal.

Item.	Area.	G from centre.	Mmt.	M.I. about centre.	
Original water-plane	3600	—	—	$\frac{1}{12} \times (300)^3 \times 12$ =	27000000
Portion lost . . .	360	120	43200	$360 \times (120)^2$ = (approximately)	5190000
Intact water-plane .	3240	$13\frac{1}{3}$	43200		21810000
				$3240 \times (13\frac{1}{3})^2$ =	576000
				M.I. about axis through new C.F. =	21234000

Transverse BM $= \dfrac{38520}{15840} = 2\cdot 43'$. Hence GM $= 1\cdot 74'$.

Longitudinal BM $= \dfrac{21234000}{15840} = 1340'$. Hence GM $= 1340'$.

Moment causing heel $= 1440 \times 3$ ft.[4]

Hence $\tan\theta = \dfrac{1440 \times 3}{15840 \times 1\cdot 74} = \cdot 157$; and heel = nearly 9°.

Moment causing trim $= 1440 \times 120$.

Hence trim $= \dfrac{1440 \times 120 \times 300}{15840 \times 1340} = 2\cdot 44'$.

The heel and trim take place about axis through the new C.F., which is situated $\frac{1}{3}'$ transversely and $13\frac{1}{3}'$ longitudinally from the centre. The central immersion is increased by—

$$\tfrac{1}{3} \times \text{angle of heel} + 13\tfrac{1}{3} \times \text{angle of trim} =$$

$$\tfrac{1}{3} \times \cdot 157 + 13\tfrac{1}{3} \times \frac{2\cdot 44}{300} = \cdot 16'.$$

Hence the draughts at the middle line are—

for'd $4\cdot 0 + \cdot 44 + \cdot 16 + 1\cdot 22 = 5\cdot 82' = 5'\,10''$
aft $\;\;4\cdot 0 + \cdot 44 + \cdot 16 - 1\cdot 22 = 3\cdot 38' = 3'\,4\frac{1}{2}''$

Note.—In the above method the water added up to the new water-line obtained by adding the mean sinkage that would be obtained with a central compartment to the original water-line is regarded as added weight. That entering the ship afterwards due to heel and trim is not included as weight; if required it is found from the additional immersion of the original C.F. due to the heel and trim about the new C.F.

In the above example the total amount of water entering the ship $= (\cdot 44 + \cdot 16) \times$ intact area of water-plane.
$= \cdot 6 \times 300 \times 12 = 2160$ cubic feet.

This is half as much again as that assumed up to the deep parallel water-line.

Note.—Alternatively, if desired, the whole of the space bilged may be regarded as lost buoyancy instead of added weight. The displacement and G are then unchanged, the position of B alone is altered. The same results are obtained for heel and trim, but the GM is greater than that found above, the product W × GM being the same.

Stability of Ship Aground.

The displacement is less than the weight; part of the support is then provided by the bottom of the ship, and is supposed concentrated at one point.

To find the stability, subtract the displacement from the weight of the ship, getting the pressure due to the ground. Find the position of the resultant support due to the pressure and to the displacement (acting at the metacentre). The

height of this point above the c.g. of the ship is the virtual metacentric height.

This is of importance when docking a ship having considerable trim by the stern, as there is a tendency to instability when the keel is on the point of touching right fore and aft.

Let W = weight of ship.

Δ = displacement when just aground fore and aft.

a = distance of ground support abaft centre of flotation.

h = height of metacentre above keel at displacement Δ.

K = height of c.g. above keel.

P = ground support in tons.

M = moment to change trim 1 inch.

δ = original trim in inches.

Then $\quad Pa = M\delta$, giving P

$\Delta = W - P$, giving Δ, and hence h.

Virtual GM $\quad = \dfrac{\Delta h}{W} - K.$

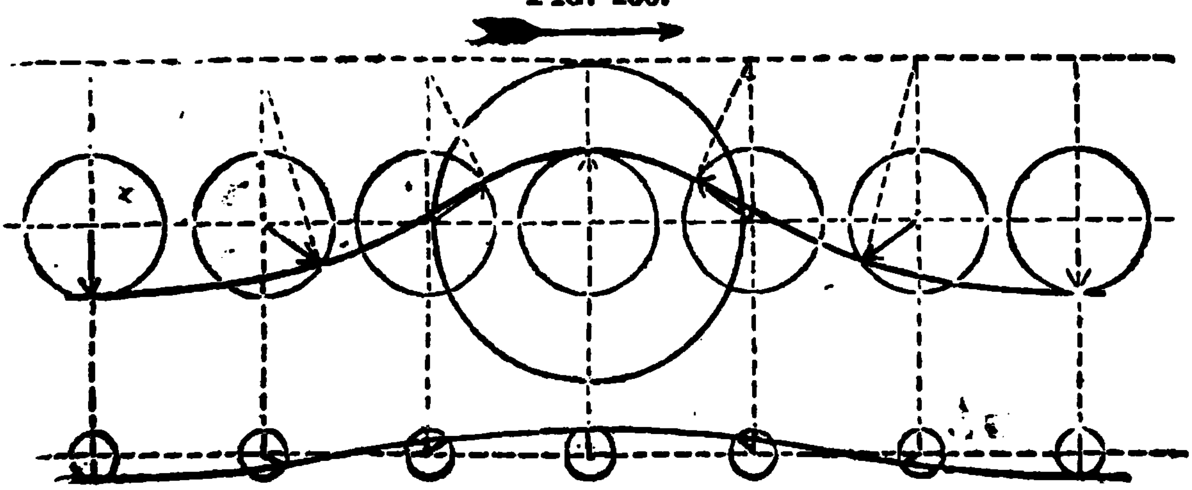
This must be positive if the ship remains stable.

WAVES.

Sea Waves.

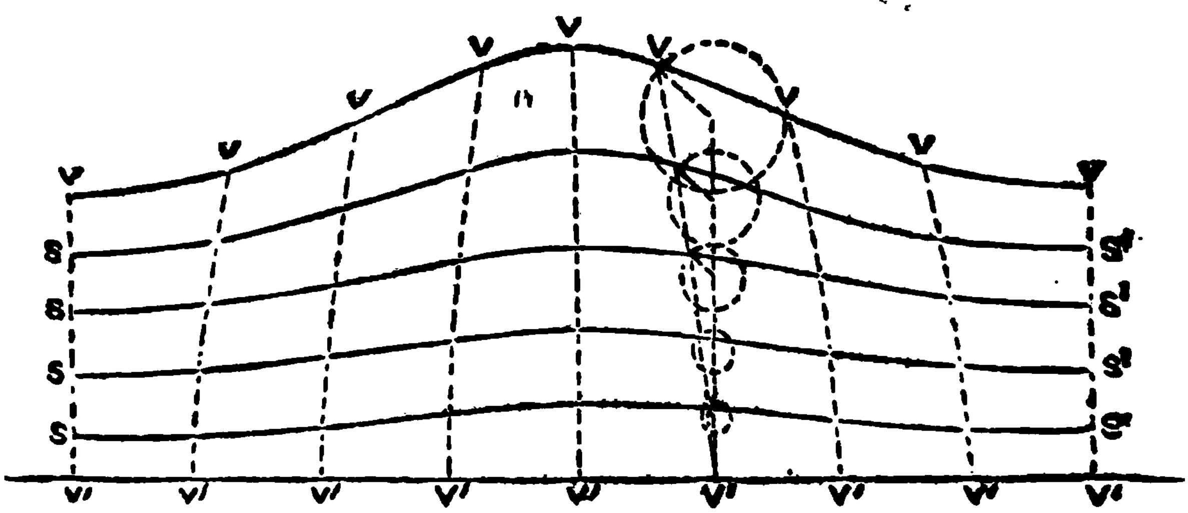
In the ordinary sea wave, or wave of oscillation, the form alone has a translatory motion, as the particles composing it revolve at a uniform rate in circular orbits, the radius of

Fig. 136.



these orbits varying with the undisturbed depth, but remaining constant for particles in any subsurface or subsurface of equal pressure horizontal when undisturbed; the form of wave-surface thus formed being trochoidal (see fig. 136), as also the form of any subsurface (see fig. 137), the only difference being that while the diameter of the rolling circle of the subsurface remains the same as for the wave-surface, the length of its tracing arm diminishes in geometrical progression in going downwards.

Fig. 187.



V, V' are columns of water which are vertical in still water.
S, S' are subsurfaces of equal pressure horizontal in still water.

Formulæ.

T = periodic time of wave in seconds.
L = length of wave in feet (from crest to crest or trough to trough).
V = velocity of advance of wave in feet per second.
V_1 = velocity of advance of wave in knots.
R = radius of rolling circle in feet.
r = radius of tracing arm for wave-surface in feet.
g = accelerating force of gravity = 32·2 nearly.
v = linear velocity of wave-surface particle in its orbit.
s = sine of steepest slope of wave-surface.
h = height of wave in feet.

$$h = 2r \qquad L = 2\pi R \qquad s = \frac{h}{2R} = \frac{\pi h}{L}$$

$$T = 2\pi\sqrt{\frac{R}{g}} = \sqrt{\frac{L}{5\cdot123}} = \frac{V}{5\cdot123} = \frac{V_1}{3\cdot04} = \frac{L}{V}$$

$$V = 5\cdot123\,T = \sqrt{5\cdot123\,L} = \sqrt{g}\,R = L/T$$

$$V_1 = 3\cdot03\,T = \sqrt{1\cdot8\,L}$$

$$L = \frac{2\pi V^2}{g} = \frac{V^2}{5\cdot123} = \frac{V_1^2}{1\cdot8} = V\,T = \frac{g\,T^2}{2\pi} = 5\cdot123\,T^2$$

$$v = \frac{\pi h}{T} = h\sqrt{\frac{\pi g}{2L}} = 7\cdot11\frac{h}{\sqrt{L}} = 16\cdot1\frac{h}{V} = 9\cdot55\frac{h}{V_1}$$

Properties of the Subsurfaces and Wave Interior.

1. *To find the ratio in which the orbits and velocities of the particles are diminished at a given depth below the wave-surface.*

Using the above symbols, in addition let
D = depth in feet of centre of orbit of subsurface particles below centre of orbit of surface particles.

r' = radius in feet of tracing arm of subsurface.
= half the height of subsurface wave.

$$\text{Then } r' = r\,e^{-\frac{D}{R}} \text{ or } \log_e \frac{r}{r'} = \frac{D}{R} \text{ or } \log_{10} \frac{r}{r'} = \frac{2\cdot73\,D}{L}$$

Note.—Approximately the orbits and velocities of the particles of water are diminished by *one-half* for each additional depth below the surface equal to *one-ninth of a wave-length.*

Example {Depth in fractions of a wave-length $0\ \frac{1}{9}\ \frac{2}{9}\ \frac{3}{9}\ \frac{4}{9}$, etc.
Proportionate velocities and diameters $1\ \frac{1}{2}\ \frac{1}{4}\ \frac{1}{8}\ \frac{1}{16}$. etc.

For table of exponential functions see pp. 708-10.

2. *To find how high the centre of the orbit of a given particle is above the level of that particle in still water.*

Multiply the square of the height by $\frac{\pi}{4}$ (·7854) and divide by the length of the wave. Symbolically the distance = $\frac{\pi h^2}{4L}$ or $\frac{r^2}{2R}$

Note.—This gives a method of calculating the area beneath a trochoid, which is the same as that up to a straight line $r^2/2R$ below the line of centres.

3. *To find the pressure at any point within a trochoidal wave.*

The pressure to which any particle is subjected in the wave is the same as that in its corresponding position in still water.

If w is the density of the water, the pressure =

$$w\left(D - \frac{r^2 - r'^2}{2R}\right) = w\left(D - \frac{r^2}{2R}\left(1 - e^{-\frac{2D}{R}}\right)\right)$$

4. *To find the mechanical energy of a mass of water of a given horizontal area and of unlimited depth agitated by waves.*

Multiply the area by one-eighth part of the square of the height of the waves and by the density of the fluid (64 lb. per cubic foot for sea water).

Note.—The exact expression for a trochoidal wave is energy $= \frac{w \times \text{area} \times h^2}{8}\left(1 - \frac{\pi^2 h^2}{2L^2}\right)$; the last term is usually negligible, and vanishes entirely in an irrotational wave. One-half of this energy is potential and one-half kinetic.

5. *To find the momentum of a wave.*

A trochoidal wave has no momentum; but an irrotational wave, and probably an actual sea wave, has forward momentum equal to $(w \times \text{area} \times h^2)/8\text{v}$, or kinetic energy $\div \frac{\text{v}}{2}$

TABLE OF THE PERIODS AND LENGTHS OF SEA WAVES.

Velocity in Knots.	Velocity in Feet per Second.	Velocity in Statute Miles per Hour.	Period in Seconds.	Radius R.	Length in Feet.
1	1·688	1·15	·33	·09	·56
2	3·376	2·30	·66	·36	2·25
3	5·064	3·45	·98	·80	5·06
4	6·752	4·60	1·31	1·43	9·00
5	8·44	5·75	1·64	2·24	14·05
6	10·13	6·91	1·97	3·22	20·2
7	11·82	8·06	2·30	4·38	27·5
8	13·50	9·21	2·63	5·72	36·0
9	15·19	10·36	2·96	7·24	45·5
10	16·88	11·51	3·29	8·94	56·2
11	18·57	12·66	3·32	10·8	68·0
12	20·26	13·81	3·65	12·9	80·9
13	21·94	14·96	4·27	15·1	95·0
14	23·63	16·11	4·60	17·5	110·1
15	25·32	17·26	4·93	20·1	126·4
16	27·01	18·42	5·26	22·9	143·8
17	28·70	19·57	5·59	25·8	162·3
18	30·38	20·72	5·92	29·0	182·0
19	32·07	21·87	6·25	32·3	202·8
20	33·76	23·02	6·58	35·8	224·7
21	35·45	24·17	6·91	39·4	247·8
22	37·14	25·32	7·24	43·3	272·0
23	38·82	26·47	7·57	47·3	297·3
24	40·51	27·62	7·90	51·5	323·6
25	42·20	28·77	8·23	55·9	351·2
26	43·89	29·93	8·56	60·4	379·8
27	45·58	31·08	8·89	65·2	409·6
28	47·26	32·23	9·21	70·1	440·5
29	48·95	33·38	9·54	75·2	472·5
30	50·64	34·53	9·87	80·5	505·7
30·35	51·23	35·0	10	81·6	512·3
33·38	56·36	38·5	11	98·8	619·9
36·42	61·48	42·0	12	117·3	737·8
39·45	66·6	45·5	13	137·9	865·8
42·49	71·7	49·0	14	160·0	1004
45·52	76·8	52·5	15	183·8	1153
48·56	82·0	56·0	16	209	1312

Shallow-water Waves.

In shallow water of uniform depth the orbit of each particle is an oval, approximately an ellipse, the orbits becoming more flattened the nearer the particles are to the bottom.

As an approximation water may be taken as *shallow* when the depth is between $\frac{5}{12}$ and $\frac{1}{36}$ of a wave-length.

Using the same symbols as with deep-water waves, in addition let H = depth of water measured from the centre of orbit of the surface particles,

then
$$V^2 = \frac{gL}{2\pi} \tanh \frac{2\pi H}{L}$$

$$T^2 = \frac{L^2}{V^2} = \frac{2\pi L}{g} \coth \frac{2\pi H}{L}$$

Note.—$\text{Tanh}\ x = \frac{\sinh x}{\cosh x} = \frac{e^x - e^{-x}}{e^x + e^x}$; $\coth x = \frac{1}{\tanh x}$

The values of these hyperbolic functions are given in the tables on pp. 708–10; for certain depths the velocity, etc., can be found from the table below.

If $\frac{H}{L}$ is more than about $\frac{5}{12}$, $\tanh \frac{2\pi H}{L} = 1$ approximately, and the formulæ become those above for deep-water waves.

If $\frac{H}{L}$ is less than about $\frac{1}{36}$, $\tanh \frac{2\pi H}{L} = \frac{2\pi H}{L}$ approximately, and then $V^2 = gH$ and $T^2 = \frac{L^2}{gH}$. The period is then very large, and the velocity is almost independent of the length.

Table of the Ratios of Waves for Shallow Water to the Corresponding Quantities for Deep Water.

Depth of Water from Centres of Orbits in Fractions of Wave's Length	Ratios			Depth of Water from Centres of Orbits in Fractions of Wave's Length	Ratios		
	Velocity for a given Length	Length and Velocity for a given Period	Length for a given Velocity		Velocity for a given Length	Length and Velocity for a given Period	Length for a given Velocity
$\frac{1}{36}$	·417	·174	5·76	$\frac{6}{36}$	·884	·781	1·28
$\frac{2}{36}$	·579	·336	2·98	$\frac{8}{36}$	·940	·884	1·13
$\frac{3}{36}$	·693	·481	2·08	$\frac{10}{36}$	·969	·939	1·06
$\frac{4}{36}$	·776	·603	1·66	$\frac{12}{36}$	·985	·970	1·03
$\frac{5}{36}$	·838	·703	1·42	$\frac{15}{36}$	·995	·989	1·01

Ripples.

For waves of less than 4 inches in length the surface tension has an appreciable effect. Using symbols as before, let

τ = surface tension of water = ·00496 lb. per linear foot in fresh water. Then $v^2 = \frac{gL}{2\pi} + \frac{2\pi g\tau}{wL} = 5{\cdot}12\,L + \frac{{\cdot}016}{L}$

Minimum velocity is 9·1 inches per second or half a mile an hour, the wave-length being then about ·67 inches.

Sea Waves.

By Lieutenant Paris.

District.	Mean Wave Height in Feet.	Period in Seconds.	Length in Feet (deduced).
Atlantic (region of trade winds)	6·2	5·8	170
South Atlantic . . .	14·0	9·5	460
Indian Ocean (south of) .	17·4	7·6	300
Indian Ocean (region of trade winds) . . .	9·2	7·6	300
Seas of China and Japan .	10·5	6·9	240
West Pacific	10·2	8·2	340

*By Dr. Vaughan Cornish.**

Some large waves observed: (1) Western Mediterranean, length 330′ × height 22′ in moderate gale; (2) China Sea, 328′ × 21′ in violent north-east storm; (3) North Atlantic, about 500′ × 30′ to 40′ in hard gale, 350′ × 30′ (maximum 43′) in strong gale; (4) North Pacific, generally smaller than the preceding; (5) South Atlantic, 770′ (mean) to 1300′ (maximum) × 40′, also 750′ × 45′; (6) South Pacific, maximum height 40′.

In addition to the above-described storm waves, long swells, whose heights are frequently about one-half those of the corresponding storm waves, are produced; during the storm they are masked by the steeper storm waves, but they degrade more slowly, and can be observed afterwards. On the south coast of England, such waves having periods of 19 to 22½ seconds (lengths 1,800′ to 2,600′) have been observed; and similarly off the north coast of Ireland with a period of 17 seconds (length 1,400′).

* From "Waves of the Sea, and other water-waves" (T. Fisher Unwin) and Cantor Lecture, published in the Journal of the Royal Society of Arts, 1914.

DIMENSIONS OF WAVES FINALLY PRODUCED IN THE OPEN SEA.

Description of Wind.	Beaufort's Number for Wind Force.	Velocity of Wind(V) in statute m.p.h.= Velocity of Wave.	Period in secs.=V÷3·498.	Length in ft.=V^2÷2·882.	Greatest average Height in ft.=V×0·7	Length÷Height= V×·600.
Strong breeze	6	25	7·2	262	17·5	15·0
Moderate gale	7	31	8·9	404	21·7	18·6
Fresh gale .	8	37	10·6	575	25·9	22·2
Strong gale .	9	44	12·6	813	30·8	26·4
Whole gale .	10	53	15·2	1180	37·1	31·8
Storm . .	11	64	18·3	1720	44·8	38·4
Hurricane *.	12	77	22·0	2489	—	—

* Breakers of this length have not been observed.

By Sir W. H. White.

Longest waves: North Atlantic, 2,750′; South Atlantic, 1,920′; Bay of Biscay, 1,300′. Longest Atlantic storm waves, 500′ to 600′.

Ratio of length to height: commonly 25. From French observations its mean value is 17 for waves under 100′ long, 20 for waves 100′ to 200′ long, and from 23 to 27 for waves 200′ to 650′ long. The minimum value (corresponding to the steepest waves) observed was: 5 for waves up to 100′ long, about 10 from 100′ to 300′, about 16 from 300′ to 650′.

APPARENT WAVE PERIOD WHEN VESSEL IS IN MOTION.

Let T' = apparent period of waves, i.e. the time elapsing between the impact of two successive waves at the crest.

V' = apparent speed of waves, i.e. the distance along a vessel's length through which the wave crest passes aft in one second (if wave passes forward V' is negative).

V_0 = speed of ship, assumed positive when *with* the wave travel, negative when *against* it.

α = angle made by course of ship with the direction of travel of wave.

L, V, T = real length, speed, and period of wave.

Then $V = (V_0 - V') \cos \alpha$; $L = V'T' \cos \alpha$; $T = V'T'/(V_0 - V')$.

If the vessel is meeting the waves, change $(V_0 - V')$ to $(V_0 + V')$ in the first and third formulæ.

ROLLING.

Unresisted Rolling in Still Water.

T = period of complete double oscillation, i.e. from starboard to port and back to starboard, in seconds.
m = metacentric height in feet.
K = polar radius of gyration about the c.g. of ship, in feet.

$$\text{Then } T = \frac{2\pi K}{\sqrt{gm}} = 1 \cdot 11\ K/\sqrt{m}$$

Note.—1. K^2 is equal to polar moment of inertia of ship about G ÷ W (displacement). K can be calculated by a laborious process ; but its value can generally be inferred with sufficient accuracy from the known periods of ships of similar type.

For many ships, including battleships, $K = \frac{1}{3}B$ approximately, where B is the greatest beam ; in that case $T = \cdot 37\ B/\sqrt{m}$. Sir J. H. Biles gives the ratio K/B as ·29 in *Paris* and *New York*, and about ·4 in large Atlantic liners.

2. (*a*) The period is reduced when the metacentric height is increased, e.g. if the GM is large in the 'deep load' condition, the period is appreciably diminished, although K is then slightly increased.

(*b*) The period is increased when the radius of gyration K is increased, i.e. when weights are winged or placed away from the centre.

Example.—A ship of 12,000 tons displacement has a metacentric height of 2·5 feet and a period of roll of 15 seconds. Find the period when additional weights are introduced aggregating 1,500 tons, whose mean position is 40 feet from the c.g. of the ship, the new GM being 2·7 feet.

$$\text{Original } K = \frac{T\sqrt{m}}{1 \cdot 1} = \frac{15\sqrt{2 \cdot 5}}{1 \cdot 1} = 21 \cdot 6'$$

Original polar moment of inertia $= WK^2 = 12000 \times (21 \cdot 6)^2 = 6700000$
M.I. of weights added $= 1500 \times 40 \times 40 = 2400000$
Total moment of inertia $= 9100000$

$$\begin{array}{c}\text{New radius of gyration} \\ \text{(neglective alteration due to shift of G)}\end{array} = \sqrt{\frac{9100000}{13500}} = 25 \cdot 9$$

$$\text{New period} = \frac{1 \cdot 1K}{\sqrt{m}} = \frac{1 \cdot 1 \times 25 \cdot 9}{\sqrt{2 \cdot 7}} = 17 \cdot 3 \text{ seconds.}$$

TABLE GIVING THE PERIODS OF ROLL OF SHIPS.

Ship.	T	Ship.	T	Ship.	T
Older battleships .	16	2nd and 3rd class cruisers	12	Steam yachts	11
Modern battleships	14	Modern light cruisers	9	Largest Atlantic liners	20
1st class cruisers .	15	T.B. destroyers	7	Cross-channel steamers	10

ALTERATION OF PERIOD WITH LARGE ANGLES OF ROLL.

The period is constant (neglecting resistance) when the GZ curve is straight.

If this be concave, as in a ship with circular sections, the period is increased at long angles; the amount when GZ is a sine curve may be seen from the table of pendulum periods on p. 86.

If the GZ curve be convex, the period is diminished at large angles. In a ship with fairly small GM and large freeboard, this may be considerable. With no initial stability, $T = \frac{K}{31a\sqrt{BM}}$ where a is the angle of roll in degrees.

PERIOD OF DIP.

T' = period of a complete dipping oscillation, i.e. including an upward, followed by a downward, movement.

T_0 = tons per inch, and W = displacement in tons.

$$\text{Then } T' = 2\pi\sqrt{\frac{W}{12T_0 g}} = \frac{1}{3\cdot 12}\sqrt{\frac{W}{T_0}} \text{ seconds.}$$

For a battleship T' is about five seconds. For many ships it is about one-third the rolling period.

AXIS OF OSCILLATION OF SHIP WHEN ROLLING.

All ships when rolling rotate about an axis which passes through or very near to the centre of gravity.

Assuming first that the resistance to rolling is small, the axis passes through G if the distance of G above all the inclined water-lines is constant. Generally, the rolling is necessarily accompanied by dipping oscillations of period $\frac{1}{2}T$ whose amount varies according to the distance from G to the mean centre of curvature of the sections near the water-line, and inversely as the amount $T^2 - 4T'^2$. Generally speaking, heavy dipping, and therefore 'uneasy' rolling, results if the wedges of immersion and emersion are very unequal, and if the period of roll approximates to twice the period of dip.

It was shown by Mr. A. W. Johns (Trans. Inst. Nav. Archs., 1909) that the resistances to rolling influence the motion of G, and cause also lateral movements; these have been determined experimentally in the *Elorn*, where the axis was found to be always slightly above G.

Resisted Rolling in Still Water.

Curve of declining angles.—If a ship be held over to a certain angle of heel and then released, it describes oscillations of diminishing amplitude. If the extreme angle Θ be noted at the end of each half-roll and plotted as ordinates to a base of the number n of single rolls (i.e. after intervals of $\frac{1}{2}$ T) from the commencement, a curve (fig. 138) drawn through the tops of the ordinates is termed a curve of declining angles.

Fig. 138.

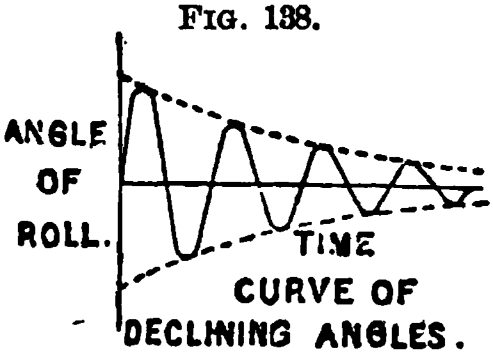
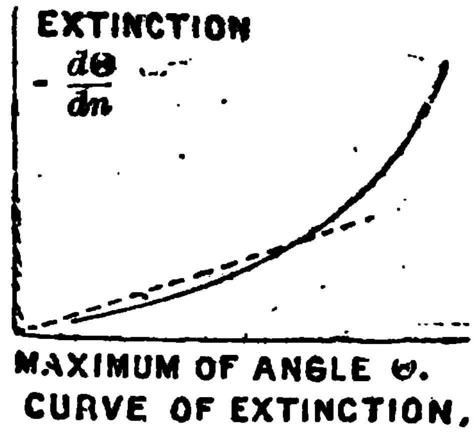


Fig. 139.



Curve of extinction.—By drawing a tangent to the curve of declining angles at an angle Θ, the reduction of Θ in a single roll, i.e. $-\frac{d\Theta}{dn}$ can be assessed. On setting up this quantity on a base of Θ the curve of extinction (fig. 139) can be drawn. In this, supposing the ordinate $-\frac{d\Theta}{dn}$ were 2° for an abscissa value of 10°, it would follow that a roll of 11° to starboard would be followed by one of 9° to port, very nearly; the difference 11° − 9° being 2°, the extinction.

Value of extinction.—The extinction varies rather irregularly with the angle Θ. Within certain limits it can generally be represented by the formula $-\frac{d\Theta}{dn} = a\Theta + b\Theta^2$, where a and b are two numerical coefficients. With a certain loss of accuracy, either coefficient can be neglected, and the whole resistance assumed represented by the other. For instance, in fig. 139, if b be neglected, as is frequently done in mathematical investigations, the resistance is assumed represented by the straight line, which is fairly accurate for small angles of roll. If the a term be neglected (as is done by French investigators), the curve in the figure would be replaced

by a parabola with axis vertical. The following values of a and b have been found (all angles in degrees):—

Ship.	Period T.	a	b
Sultan	17·75	·027	·0016
Devastation	13·5	·072	·0150
Inconstant	16·0	·035	·0051
Inflexible	10·7	·040	·008
Revenge, with bilge keels (200′ × 3′ each side)	15·5	·065	·017
„ without bilge keels	15·2	·0123	·0025
Greyhound, with bilge keels (100′ × 3½′ each side)	7·75	·0198	·0462
„ without bilge keels	7·75	·044	·0032
Elorn (tug)	4·5	—	·016
Modern battleship (small angles)	13·5	·15	—*

To find the angle of roll after n single rolls.

Let Θ = angle of roll after n single rolls.
α = angle of roll at commencement.
a, b = coefficients of extinction, as above.

Then $\Theta = \dfrac{a/b}{\left(1+\dfrac{a}{b\alpha}\right)e^{an}-1}$; or conversely $n = \dfrac{1}{a}\log_e \dfrac{1+\dfrac{a}{b\Theta}}{1+\dfrac{a}{b\alpha}}$

If $b = o$, $\Theta = \alpha e^{-an}$; or $n = \dfrac{1}{a}\log_e \dfrac{\alpha}{\Theta}$

If $a = o$, $\Theta = \dfrac{\alpha}{1+\alpha bn}$; or $n = \dfrac{\alpha-\Theta}{\alpha b\Theta}$

Tables of exponential functions and hyperbolic logarithms are given on pages 708–15.

Work done in extinction.

Let W = displacement in tons.
m = metacentric height in feet.
Θ = mean angle of roll in circular measure.
$\Delta\Theta$ = decrement of roll in a single swing.
b' = value of b coefficient for circular measure.
$= \dfrac{180b}{\pi} = 57\cdot3b$. ($a$ is unaltered.)
ω = angular velocity of ship in circular measure per second.

The energy lost $= \text{W}m\Theta \,.\, \Delta\Theta$ ft.-tons.
$= \text{W}m\Theta\,(a\Theta + b'\Theta^2)$.

* Angle of roll was too small to determine b.

If the resistance be supposed due in part to a couple varying directly as the angular velocity, and in part to one varying as its square, i.e. resisting moment $= K_1\,\omega + K_2\,\omega^2$, then, approximately,

work done in single roll $= \pi^2 K_1\,\Theta^2/T + \dfrac{16\pi^2}{3} K_2\,\Theta^3/T^2$.

Since work done = energy lost, $a = \dfrac{\pi^2 K_1}{WmT}$, $b^1 = \dfrac{16\pi^2 K_2}{3WmT^2}$, or $b = \dfrac{4\pi^3 K_2}{135\,Wm\,T^2}$

The resistances represented by K_1 or a are actually non-existent, but the assumption accounts for the energy of the waves propagated and for the virtual increase of polar moment of inertia of ship caused by the concomitant movement of the water.

The resistances represented by K_2 or b are those due to bilge keel, deadwood, and frictional resistance.

Note.—In all cases the motion of a ship can be represented by a model of $\frac{1}{n}$ the linear dimensions, $\frac{1}{n^3}$ the weight, and $\frac{1}{\sqrt{n}}$ the period.

Investigation with b coefficient absent.—The motion of a ship can be completely investigated when the resistances can be assumed to follow the linear law, so that $-\dfrac{d\Theta}{dn} = a\Theta$.

In that case, if θ be the angle after time t, Θ being the initial roll, $\theta = e^{-\frac{2at}{T}} \sin \dfrac{2\pi t}{T} \sqrt{1 - \dfrac{a^2}{\pi^2}}$

The successive rolls diminish in geometrical progression, and the period of oscillation is slightly increased—approximately by $\dfrac{a^2 T}{2\pi^2}$

Bilge Keels.

The effect of bilge keels on the *Revenge* and *Greyhound* is shown in the table, p. 153. At sea they reduced the rolling in those ships by one-half. It was found that the period was slightly increased.

The extinctive effect of a bilge keel cannot be directly calculated, since its resistance is enhanced by the contrary movement of the water round the bilge. Generally speaking, it should be placed slightly above the turn of the bilge, and made as deep as practicable. Since its efficacy varies as the square of its distance from the axis of roll, it should generally be not much longer than one-half the ship's length. To reduce increase of resistance to motion ahead, it is placed in a diagonal plane passing through the axis of oscillation.

When in motion ahead, the extinction is in all cases

increased; at 12 knots in *Revenge* by 40%, in a T.B. destroyer by 100%.

In practice the length of bilge keels varies from one-half (in large warships) to one-third (in destroyers and merchant vessels) of the ship's length. The usual depth is about $\frac{1}{30}$ the beam, slightly more in warships; in lightships $\frac{1}{3}$ beam (see paper, Trans. I.N.A., 1912, by G. Idle and G. S. Baker).

Heel due to Gunfire.

W = displacement in tons.
m = metacentric height in feet.
w = weight of projectile in pounds.
w' = weight of charge in pounds.
h = height of gun above water in feet.
T = period of double roll in seconds.
D = mean draught in feet.
v = muzzle velocity of projectile in ft./sec.
a = angle of initial roll in degrees.

$$a = \frac{(w + \frac{3}{8}w')\, v\, (h + \frac{1}{3}D)}{200\, WTm}$$

Rolling among Waves.

Effective wave slope.—This is the slope perpendicular to which a ship, moving among waves, tends to place herself. Little is known of its actual amount; but it was stated by W. Froude that it was approximately the slope of the wave subsurface through the centre of buoyancy of the ship. With large ships the slope does not generally exceed 3° or 4°.

If T_1 is the apparent period of a simple wave, and a the maximum wave slope, then the wave slope at any instant is $a \sin\left(\frac{2\pi t}{T_1} + \gamma\right)$, where γ is the initial slope. T_1 is determined by the methods of p. 144; it depends on the speed and course of the ship as well as on the dimensions, etc., of the waves. If the ship's length is perpendicular to the direction of wave advance, a is equal to $\pi H/L$, where H is the height and L the length of the wave subsurface. If the ship is partly along the waves, a is diminished; approximately a varies as the cosine of the angle of obliquity.

In a complex sea the wave structure is assumed divisible into simple waves of the type described, and the effects of each component wave are superposed.

Rolling in a simple component wave.—It is assumed that the resistance to rolling is due solely to an 'a coefficient', i.e. that it is directly proportional to the angular velocity. By choosing a suitable value of a, the still water decremental equation $-\frac{d\Theta}{dn} = a\Theta$ can be made to represent, within limits of Θ, the actual decrement; the error, when large, provides a limit to the usefulness of the investigation, and to the accuracy of the results.

The wave slope being $\alpha \sin 2\pi t/T_1$, the inclination θ of the ship is found to consist of the sum of two terms—

1. $Ae^{-\frac{2at}{T}} \sin\left(\frac{2\pi t}{T}\sqrt{1-\frac{a^2}{\pi^2}}+\beta\right)$, termed the 'free' roll,

which is exactly the same as the natural roll of a ship in still water. This oscillation is arbitrary in initial amplitude (A) and phase (β), but the former diminishes in geometrical progression for successive rolls.

2. $$\alpha \sin\left(\frac{2\pi t}{T_1} - \tan^{-1}\frac{\frac{2a}{\pi}\cdot\frac{T}{T_1}}{1-\frac{T^2}{T_1^2}}\right) \div \sqrt{\left(1-\frac{T^2}{T_1^2}\right)^2 + \frac{4a^2}{\pi^2}\frac{T_1^2}{T_1^2}}$$

termed the forced roll, which is in the period T_1 of the wave. The phase of this is such that among short waves the ship rolls *against* the wave slope, but slightly in advance of the direct opposite; among long waves the ship rolls *with* the wave slope, with a slight time lag; at or near synchronism, when the ship's period T is nearly equal to the wave period T_1, there is a phase difference of about 90°, i.e. the ship reaches her greatest inclination when the wave slope is zero or very small. The variation of the amplitude of the forced roll is shown in the highest curve on fig. 140, the value of a being ·157. Among short waves, or equally when the ship's period is relatively large, the rolling is very small; at synchronism it is very large; among long waves, or when the ship's period is relatively small, the rolling is reduced but is always more than the effective wave slope. The dotted curve in the figure is the corresponding forced roll when the resistance is absent, showing the resistance has comparatively little effect on the forced roll, except near synchronism.

Theoretically the free roll should die out almost immediately, leaving only the forced roll; actually, a ship rolls generally in her own period, showing that it is continually re-introduced by irregularities in the waves. Increase of a, i.e. of the resistance, is therefore beneficial in restricting the free roll component; resistance also operates in other ways, e.g. by increasing b and lengthening the period.

General Conclusions.

1. To diminish rolling among waves, a ship's natural period should be as large as possible; hence, her metacentric height should be small, and her weights 'winged' or removed as far as practicable from the centre.

2. In such conditions a ship will roll *against* the waves, showing the necessity for a sufficient range of stability, since her virtual angle of heel is greater than her inclination from the vertical.

3. For a ship to roll with the waves, her period should be small, and her metacentric height large, so that she will float like a raft. The gain in safety and seaworthiness in such conditions is, however, more apparent than real, except in very small boats, as the vessel is likely to meet small supplementary waves which may synchronise and cause heavy and dangerous rolling.

4. Heavy rolling is caused by the periods of wave and ship being approximately equal; it may generally be obviated by a change in speed or course of the ship, which alters T_1, the apparent wave period.

5. Resistances, e.g. those provided by bilge keels, are chiefly operative in preventing heavy rolling during approximate synchronism. They serve also in moderating the rolling in all conditions; but no considerable limitations of the rolling experienced among non-synchronous waves can be ensured by any practicable resistance, however large.

6. Owing to the coexistence of forced and free rolls, the combined roll generally consists of groups of rolls which start and end in comparative quiescence, and attain a maximum in the middle. The period of the group is approximately $\pm \frac{TT_1}{T - T_1}$; the maximum roll is λ times the forced roll, where λ lies between 1 and 2, being equal to $1 + e^{-aT_0/T}$, where T_0 is the group period.

Effect of Water Chambers on Rolling.

These were found by Sir Philip Watts to favour the reduction of moderate rolling, against which bilge keels are comparatively inefficient.

Fig. 140 shows the effect of water chambers of closed channel type, determined from theoretical considerations (see paper by L. Woollard, Trans. Inst. Nav. Archs., 1913). The ship has an a coefficient of extinction of ·157; the water in the channel is also resisted, the corresponding a coefficient being π times the values given for K_2/p. The curves represent the ship's forced roll on a base of T_1/T or wave period ÷ ship's period. The 'damping coefficients' marked on the curves are equal to $\frac{1}{\pi}$ times the corresponding a coefficients of the free roll, which in this case vary, being augmented when the water is throttled in the channel.

The conclusions derived are briefly as follows:—

1. The tank should be placed as high as possible in the ship; the horizontal portion in particular should be near, or above, the ship's centre of gravity.

2. The period of the tank depends on its shape, particularly the area of the constricted channel; it is almost independent

FIG. 140.

MAXIMUM ANGLES Θ OF FORCED OSCILLATION OF SHIP.

Curve I′. No tank, no resistance to rolling.
Curve I. No tank, ship resisted ($\kappa_1/p = \cdot 05$).
Curve II. With tank of period ·89 that of ship, resistance coefficient (κ_2/p) = ·06
Curve III. ,, ,, ,, ,, ·25
Curve IV. ,, ,, ,, ,, ·50
Curve V. ,, ·71 ,, ,, ·25

Note.—The ordinates of the curves represent values of Θ/α or

$$\frac{\text{Maximum angle of ship's forced oscillation}}{\text{Angle of virtual slope of wave}}$$

of the amount of water contained, and of the degree to which the flow is resisted.

3. The rolling will be a minimum when the period of the tank is rather less than the apparent period of the waves meeting the ship.

4. A tank having a period capable of adjustment would, therefore, if practicable, prove advantageous; failing this, the tank period should be made about 70 per cent of the ship's period in large ships.

5. A moderate resistance to the flow of water in the tank is on the whole favourable, e.g. the flow can well be throttled until the amplitude of movement is reduced by one-half after each single oscillation.

6. The tank is useless or disadvantageous among very short waves, and should then be put out of action.

PITCHING.

The considerations governing the pitching of ships are largely the same as those affecting the rolling; but there are the following differences:—

(*a*) The period of pitching is relatively small, being in most ships slightly more than half the rolling period. It is governed by the same formula, being increased by placing weights at the ends of the ship, and diminished by an increase in longitudinal stability. In applying the formula of p. 150 to find the period of pitching, take K to be about $\frac{1}{4}$L.

(*b*) The vertical wave slope a is small, particularly when the ships are long in comparison with the length of the waves. It is a maximum when the ship is head or stern to waves, though she may be turned through a considerable angle in each direction without greatly reducing a.

(*c*) Comparatively little is known of the resistance to pitching, except that it is augmented by full ends, by flare at the bows, and by flatness at the stern.

(*d*) The period of pitching is too small to enable it to be made large in comparison with the wave period, as is done for rolling; it is also desirable that the vessel should pitch *with* the waves, so that the bow and stern rise and fall with the water. The ratio T/T_1 is therefore made as small as possible; and weights are brought longitudinally as near the centre as convenient in order to reduce the pitching period.

(*e*) With these conditions satisfied, a vessel at rest, or running before the sea, generally follows closely the effective wave slope. This is also the case with a ship head to sea up to a certain speed, at which the apparent wave period is shortened sufficiently to approach synchronism with the ship's pitching period. The pitching then increases, and continues to do so as the speed is raised, since the synchronising conditions would rarely be reached and passed.

Observations of Rolling.

When observations are made by batten, or a constant direction maintained by a gyroscope, no special errors arise. Pendulums are convenient, but are liable to special errors as follows :—

Let θ be the true angle of ship to vertical.

$\theta + \phi$ be the actual angle recorded, ϕ being the error in excess.

T be the still water rolling period of ship in seconds.

T_1 be the apparent wave period in seconds.

a be the virtual slope of wave.

l be length of pendulum in feet.

1. In still water any pendulum hung from the centre of oscillation (i.e. near the ship's centre of gravity) will indicate correctly the angles of roll. It may be hung from any point at the same height towards the side without large error. If hung from a point h feet above the c.g., $\phi = 4\pi^2 h\theta/gT^2$, or $\phi/\theta = 1 \cdot 23h/T^2$ with a short pendulum, the error being in excess. With a longer pendulum $\phi/\theta = 1 \cdot 23h/(T^2 - 1 \cdot 23l)$; the error is in defect with very long pendulums. The height h should be made sufficiently small for this error to be negligible.

2. Among waves a long period pendulum hung at the c.g. indicates the correct vertical, and a short period pendulum the effective vertical, i.e. the perpendicular to the effective wave slope. For a length l, the error is given by $\phi = \pm agT_1^2/(gT_1^2 - 4\pi^2 l)$ or $\phi/a = \pm T_1^2/(1 \cdot 23l - T_1^2)$. To reduce this error to reasonable limits a pendulum of very long period must be employed—in general a delicately balanced compound pendulum of equivalent period ($2\pi\sqrt{l/g}$).

For example, among waves of 6 seconds period, $\phi = a$ if l is small or if $l = 59$ feet, so that a pendulum 60 feet long will cause the same amount of error, though in the opposite sense, as one of a few feet in length. To limit the error to $a/10$, a pendulum of length 320 feet is necessary, which can only be ensured by using a compound pendulum of equivalent period, i.e. twenty seconds.

In the Mallock rolling indicator the period of the pendulum is forty seconds.

3. The two errors of a short period pendulum incorrectly placed may be made to neutralize in certain conditions; where such an instrument only is available, it should be placed about mid-draught in the majority of ships, where it may serve for rough indications of rolling.

SPEED AND HORSE-POWER.

General Remarks.

Note.—Unless otherwise defined, V always represents speed of ship in knot; 1 knot = 6,080 feet per hour.

The horse-power required to drive a ship at a certain speed cannot be assessed by any mathematical calculation alone. It can be deduced from observations obtained from similar ships or models; in some cases it can be estimated with fair accuracy from the performances of other ships having forms resembling, though not exactly similar to, the one desired.

Indicated horse-power (I.H.P.) is the power actually exerted in the engines. In reciprocating engines it is calculated from the areas of the indicator diagrams. It cannot be directly measured in turbines.

Shaft horse-power (S.H.P.) is the power transmitted by the shafts. It is measured by means of a torsion-meter which indicates the small twist in the shaft over a short length. The shaft is calibrated previously, whence the torque corresponding to the twist and the power are readily calculated. This affords the only means of measuring the power exerted in turbine engines; in reciprocating engines, the S.H.P. is usually about 85% of the I.H.P., the difference being due to frictional losses in engine, thrust blocks, and shaft bearings forward of the torsion-meter.

Effective horse-power (E.H.P.) is that required to tow the naked hull (i.e. without propellers, shaft supports, or rudder) through still water.

The difference between E.H.P. and I.H.P. or S.H.P. is accounted for by (*a*) the losses at the propeller, (*b*) the friction of engine and shaft (in part only if S.H.P. be considered), (*c*) the resistance of appendages, (*d*) the interaction between propeller and hull. The effect of the last is usually small.

The resistance (R) is the force required to tow the hull, as above. If this is expressed in pounds, E.H.P. $= \text{RV}/326$.

Propulsive Coefficient.

The propulsive coefficient (μ) is the value of the ratio $\dfrac{\text{E.H.P.}}{\text{I.H.P.}}$ for ships with reciprocating engines, or $\dfrac{\text{E.H.P.}}{\text{S.H.P.}}$ for turbine driven vessels.

It is of the greatest importance that μ should be predicted as accurately as possible when powering a ship, but it is very difficult to estimate it directly. It is preferable in a new design to adopt a value of μ based on that obtained from a ship of fairly similar type having engines working under somewhat similar conditions. Allowance should be made for any difference in the circumstances in the two cases (e.g. a change in the speed of revolution may affect the propeller efficiency, etc.).

The propulsive coefficient is equal to the product of 4 factors:—

1. *Engine and shaft efficiency.* This is from ·82 to ·88 in most screw ships, nearly 1 in turbine-driven ships (based on S.H.P.), and about ·8 in paddle steamers. At low speeds these ratios are smaller.

2. *Propeller efficiency.* This can only be estimated by designing the propeller; about ·70 is the greatest possible value (see p. 192).

3. *Hull efficiency,* depending on the interaction of hull and screw (see below).

4. *Ratio of resistance of naked hull to that with the appendages.* The appendages form a serious part of the resistance in many ships. The effect of shaft bossings is given by Mr. Luke (Trans. I.N.A., 1910). As regards rudders, Mr. T. G. Owens (Trans. I.N.A., 1914) gave the following comparative results for a 25,000 ton ship at 25 knots, having balanced rudders :—

Number of Rudders.	Arrangement.	Total Area ÷ Area of Longitudinal Immersed Plane.	Percentage Increase of Resistance caused by Rudder over Naked Hull.
1	—	$\frac{1}{50}$	1·3
2	Tandem on middle line	$\frac{1}{46}$	2·3
2	Twin, side by side	$\frac{1}{32 \cdot 5}$	7

These data are useful as a basis of comparison between two vessels.

General remarks on propulsive coefficient.—Cet. par. μ is usually highest in high speed ships, and in a given ship it increases with the speed; but there are many exceptional cases, as, for instance, where the propeller efficiency is diminished by excessive slip at certain speeds, leading to a reduction in μ.

μ is generally rather greater for single screws than for twin screws (*v.* hull efficiency).

In turbine-driven vessels, the high speed of shaft necessary to obtain good turbine efficiency leads to a considerable reduction in the propeller efficiency. The propulsive coefficient is then commonly equal to or even less than that obtained with reciprocating engines, in spite of the gain in the first factor of μ (engine and shaft efficiency) due to the non-inclusion of most of the machinery loss in turbines. Geared turbines permit a variation between the revolutions of turbine and propeller shaft and enable the efficiency of them both to be greatly improved.

The following table gives the propulsive coefficients typical vessels of a variety of classes. In general the coefficients have been obtained in favourable circumstances, even after several modifications in the propellers. It desirable, therefore, to adopt, when powering a new ship, value of μ less than that given below by from $2\frac{1}{2}$ to 5 per ce of the whole (i.e. from 5 to 10 per cent of itself); this wi provide a margin for eventualities or unfavourable condition

Type of Ship	Number of Screws.	$\frac{\text{V (knots)}}{\sqrt{\text{L feet}}}$	Propulsive coefficient μ.	Wake Factor w.	Thrust Deduction t	Hull efficiency.	Remarks.
Battleship (turbine)	4	·94	·47	·15	·12	1·01	Inne
				·20	·16	1·01	Oute
„ (reciprocating)	2	·92	·47	·14	·17	·95	
Battle cruiser (turbine)	4	1·1	·52	·13	·10	1·02	Inne
				·19	·12	1·05	Oute
1st class cruiser (recip.)	2	1·09	·53	·10	·10	·99	
2nd class „ „	2	1·02	·48	·06	·10	·95	
3rd class „ „	2	1·08	·48	·05	·08	·97	
T.B. destroyer (recip.)	2	1·7	·61	–·01	·04	·97	
„ (turbine)	3	1·75	·52	·04	·05	·99	Inne
				·02	·05	·97	Oute
Mail steamer (turbine)	4	·92	·46	·30	·17	1·08	Inne
				·22	·20	·95	Oute
Cargo vessel	2	·8	·48	·20	·15	1·02	
„ „	1	·8	·53	·34	·17	1·11	
Sloop	1	·96	·45	·21	·17	1·00	
Steam Pinnace	1	1·5	·50	·10	·15	·94	
Submarine (in surface)	2	—	—	·16	·10	1·04	
„ (diving)	2	—	—	·20	·12	1·05	

Wake and Thrust Deduction.

A moving ship is surrounded by a current of water whic is moving, on the whole, in the same direction as the ship This current is termed the *wake.*

The speed of the wake varies from point to point; th magnitude of its forward velocity is of particular importanc near the propellers. This velocity is assessed from mode experiments by comparing (*a*) the speed V of the screw when moving with the ship in its correct position and rotatin so as to exert the proper thrust; and (*b*) the speed V_1 a which the screw must be run in the open at the same numbe of revolutions so as to exert the same thrust. Evidently th screw acts as if there were a forward current $V-V_1$; this is termed the wake velocity. The fraction $\frac{V-V_1}{V_1}$* is termed th the *wake factor* and denoted by w. Hence $V = V_1(1+w)$.

* The nomenclature devised by Mr. Froude is here followed; Mr. D. W Taylor defines wake factor as $\frac{V-V_1}{V}$, which is equal to $\frac{w}{1+w}$

The screw exercises a suction on the stern of the ship, augmenting the resistance from R (without screw) to T (with screw). T is thus the actual thrust exerted by the screw when propelling the ship. The ratio $\frac{T-R}{T}$ is denoted by t, and termed the *thrust deduction coefficient*. Hence $R = T\,(1-t)$.

The effective power of the screw, or the rate at which it does useful work is TV_1; the power required to tow the ship (i.e. E.H.P. augmented to include effect of appendages) is RV. The ratio $\frac{RV}{TV_1}$ or $(1 + w)\ (1 - t)$ is termed the *hull efficiency*.

The values of w and t are of importance in propeller design; the hull efficiency is a factor of the propulsive coefficient, and thus directly affects the determination of the power. Average values for different types of ship are included in the above table.

From model experiments made by Mr. W. J. Luke, the following conclusions may be drawn (Trans. I.N.A., 1910 and 1914):—

With single screws decrease in wake and hull efficiency followed increase in diameter. With twin screws, outward turning, the reverse was experienced.

Twin screws should be placed laterally as near the hull as practicable.

Outward turning screws are much preferable to inward turning when the effect of shaft bossing is included. Such bossing should be placed as nearly normal to the surface as possible.

The adoption of contrary turning screws of equal pitch on a common axis may increase the propulsive coefficient by 15 or 20 per cent of itself with a full model (block coefficient ·65); the gain was much smaller with a fine model (block coefficient ·60).

Mr. D. W. Taylor has suggested the formulæ:—

$\frac{w}{1+w} = t = -\cdot 2 + \cdot 55\beta$ (hull efficiency 1) for twin screw ships, and

$\frac{w}{1+w} = -\cdot 05 + \cdot 5\beta$ (hull efficiency rather more than 1) for single screw ships as an average; β is the block coefficient.

With quadruple screws Mr. Luke also gave the following results, which show the relative advantages of inward and outward turning:—3-bladed screws, 4″ diameter, 1·0 pitch ratio, ·6 disc area ratio. After screws 3″ before A.P., 8″ from centre line; for'd screws 18″ before A.P., 7″ from centre line. Immersion to tips 3″; clearance from hull ½″.

Screw.	Wake w.	Thrust deduction t.	Hull efficiency.
After screws (O)			
(*a*) Without for'd screws . .	·21	·14	1·04
(*b*) With for'd screws (O) . .	·16	·13	1·01
(*c*) „ „ (I) . .	·13	·12	·99
After screws (I)			
(*a*) Without for'd screws . .	·20	·11	1·07
(*b*) With for'd screws (O) . .	·15	·12	1·01
(*c*) „ „ (I) . .	·10	·10	·99
For'd screws (O)			
(*a*) Without after screws . .	·24	·13	1·08
(*b*) With after screws (O) . .	·22	·13	1·06
(*c*) „ „ (I) . .	·22	·12	1·07
For'd screws (I)			
(*a*) Without after screws . .	·24	·10	1·12
(*b*) With after screws (O) . .	·23	·12	1·08
(*c*) „ „ (I) . .	·23	·10	1·10

O = Outward turning; I = Inward turning.

Components of Resistance.

The tow-rope resistance R of the naked model is divisible into 4 parts: (1) skin friction; (2) wave-making resistance; (3) air resistance; (4) eddy resistance.

The air resistance is small and is usually neglected; in the extreme case of a large mail steamer with high freeboard it is estimated to be 4% of the whole. Against a head wind this proportion would be much larger; the resistance would then be further augmented to an indeterminate extent by waves and rough water.

Eddy resistance is caused by discontinuities in a longitudinal sense, particularly in fittings that have blunt endings aft. In bilge keels, shaft brackets or bossings, rudders, propeller bosses, and any other appendages it is frequently present, but is then included in the difference between E.H.P. and engine power. Eddy resistance in the naked hull (which is all that is dealt with here) only occurs rarely, and is then due to badly formed sterns or water-line endings. Any abrupt or rather quick change in the direction of the after water-lines or buttocks may lead to the formation of eddies (see p. 174).

It is usual to include wave-making and eddy resistance in one group, which is termed *residuary resistance.*

SKIN FRICTION.

The resistance due to skin friction is estimated from data obtained by experiments on planks by W. Froude. He deduced the formula—$R_f = f S V^n$; where R_f = frictional resistance, V = speed of plank (or ship), S = wetted surface, f, n = coefficients depending on the nature and length of the surface and liquid density and temperature.

The values of f and n can be deduced from the following table.

Froude's Resistances per square foot in lbs. of various Surfaces at 600 *feet per minute.*

Nature of Surface	Length of surface or distance from cutwater in feet					
	2 feet			8 feet		
	A	B	C	A	B	C
Varnish	2·00	·41	·390	1·85	·325	·264
Paraffin	1·95	·38	·370	1·94	·314	·260
Tinfoil	2·16	·30	·298	1·99	·278	·263
Calico	1·93	·87	·725	1·92	·626	·504
Fine sand	2·0	·81	·690	2·00	·583	·450
Medium sand	2·0	·90	·730	2·00	·625	·488
Coarse sand	2·0	1·10	·880	2·00	·714	·520

Nature of Surface	Length of surface or distance from cutwater in feet					
	20 feet			50 feet		
	A	B	C	A	B	C
Varnish	1·85	·278	·240	1·83	·250	·226
Paraffin	1·93	·271	·237	—	—	—
Tinfoil	1·90	·262	·244	1·83	·246	·232
Calico	1·89	·531	·447	1·87	·474	·423
Fine sand	2·00	·480	·384	2·06	·405	·337
Medium sand	2·00	·534	·465	2·00	·488	·456
Coarse sand	2·00	·588	·490	—	—	—

Columns A give the power of the speed to which the resistance is approximately proportional. Columns B give the mean resistance per square foot of the whole surface of a board of the lengths stated in the table. Columns C give the resistance in lbs. of a square foot of surface at the distance sternward from the cutwater stated in the heading.

Coefficients for Computing Effective Horse-power required to overcome Skin Friction based on Mr. Froude's Constants. (Corresponds to varnish on model, or clean bottom on ship. The constants in previous table show effect of fouling.)

If S is the wetted surface in square feet then

E.H.P. = f S, where f has the value given below.

Speed in Knots.	Length of Ship in Feet.								
	100	150	200	300	400	500	600	800	1000
40	·9490	·9343	·9271	·9181	·9109	·9049	·8989	·8890	·8792
39	·8835	·8698	·8631	·8547	·8180	·8424	·8356	·8276	·8185
38	·8209	·8082	·8020	·7942	·7830	·7828	·7776	·7691	·7606
37	·7611	·7494	·7436	·7361	·7306	·7253	·7209	·7130	·7051
36	·7047	·6938	·6885	·6818	·6765	·6720	·6675	·6603	·6530
35	·6508	·6407	·6358	·6296	·6247	·6206	·6164	·6097	·6030
34	·5995	·5902	·5857	·5800	·5755	·5707	·5679	·5617	·5555
33	·5499	·5414	·5372	·5320	·5278	·5243	·5208	·5151	·5094
32	·5050	·4972	·4924	·4886	·4848	·4816	·4784	·4732	·4680
31	·4624	·4552	·4517	·4473	·4438	·4409	·4379	·4322	·4274
30	·4210	·4145	·4113	·4073	·4041	·4014	·3988	·3944	·3900
29	·3826	·3767	·3738	·3702	·3673	·3649	·3624	·3585	·3546
28	·3466	·3412	·3383	·3353	·3327	·3305	·3283	·3247	·3211
27	·3126	·3078	·3054	·3025	·3001	·2981	·2961	·2929	·2897
26	·2811	·2767	·2746	·2719	·2698	·2680	·2662	·2683	·2604
25	·2516	·2477	·2458	·2434	·2415	·2399	·2383	·2357	·2331
24	·2242	·2207	·2190	·2169	·2152	·2138	·2124	·2101	·2078
23	·1988	·1957	·1942	·1923	·1908	·1895	·1882	·1831	·1841
22	·1753	·1726	·1713	·1696	·1688	·1672	·1661	·1643	·1625
21	·1537	·1514	·1502	·1487	·1476	·1466	·1456	·1440	·1424
20	·1340	·1319	·1308	·1290	·1286	·1277	·1263	·1254	·1241
19	·1159	·1141	·1132	·1121	·1112	·1105	·1098	·1086	·1074
18	·0995	·0979	·0972	·0962	·0955	·0948	·0942	·0931	·0921
17	·0846	·0833	·0827	·0819	·0812	·0807	·0802	·0793	·0784
16	·0713	·0702	·0697	·0690	·0685	·0680	·0675	·0668	·0661
15	·0594	·0585	·0580	·0575	·0570	·0567	·0563	·0557	·0551
14	·0489	·0481	·0478	·0473	·0469	·0466	·0463	·0458	·0453
13	·0397	·0390	·0387	·0384	·0381	·0378	·0375	·0371	·0367
12	·0315	·0312	·0309	·0307	·0304	·0302	·0300	·0296	·0293
11	·0246	·0243	·0241	·0239	·0237	·0235	·0233	·0231	·0228
10	·0188	·0185	·0184	·0183	·0181	·0180	·0179	·0176	·0174

Wetted Surface.

The wetted surface is determined by the methods indicated in pp. 57, 58. That due to appendages, e.g. bilge keels, is easily calculated and added on.

Approximate rules are :—

1. Surface $= 1 \cdot 7\,\text{LD} + V_0/\text{D}$ (Denny's).
2. Surface $= 15 \cdot 6 \sqrt{\text{WL}} = 2 \cdot 64 \sqrt{V_0 \text{L}}$ (Taylor's).
3. Surface $= 3 \cdot 4\, V_0^{\frac{2}{3}} + \frac{1}{2}\, \text{L} V_0^{\frac{1}{3}}$.

L = length, D = mean draught, V_0 = volume of displacement, W = displacement in tons.

The first formula is generally the most accurate ; the others are only reliable for warship forms.

The surface can also be determined from Blechynden's formula for mean girth (Trans. I.N.A., 1888).

4. Mean girth $= \cdot 95 \gamma \text{M} + 2\,(1 - \gamma)\,\text{D}$.

γ = prismatic coefficient of fineness, M = midship wetted girth.

Power absorbed in Skin Friction.

The power absorbed in skin friction is about three-quarters the total E.H.P. in ships of moderate speed. At the highest speeds of fast vessels it constitutes about 40 per cent of the whole effective power. It is therefore important, particularly with ships of moderate speed, that the form should be arranged so as to avoid unduly increasing the wetted surface, on which the friction depends.

The following broad principles affecting variation of wetted surface with change of dimensions have been enunciated by Mr. D. W. Taylor :—

(*a*) For a given displacement, surface varies nearly as the square root of the length.

(*b*) For a given displacement and length, surface varies only slightly within limits of beam and draught possible in practice. The most favourable ratio of beam to draught is a little below 3. [Extreme proportions of B/D, such as are obtained with shallow draught vessels, increase the surface, e.g. 6 : 1 may increase it by 15%.]

(*c*) For a given displacement and dimensions the surface is affected very little by minor variations of shape, etc. Extremely full sections are somewhat, and extremely fine sections are quite, prejudicial to small surface.

(*d*) Next to length, the most powerful controllable factor affecting wetted surface is probably that of deadwood.

RESIDUARY RESISTANCE.

This consists almost entirely of the resistance absorbed in wave-making.

The waves accompanying a ship in motion are divisible into two classes—transverse and diverging. The former have transverse crests, spaced at the longitudinal distance appropriate to their speed, which is the speed of the ship. The crests of the latter form an angle of 30° or 40° with the middle line of the ship ; they advance perpendicularly to the crests with a velocity equal to the component of the speed of the ship in that direction.

Both the bow and the stern form a system of transverse and diverging waves. The residuary resistance of the ship corresponds to the energy expended in maintaining the combined system of waves.

The diverging waves leave the ship immediately on formation ; the resistance due to them is thus the sum of the resistances due to the bow and stern systems taken separately.

The bow transverse system spreads directly sternward, and at the stern combines with the stern transverse system. If the crests of one system coincide approximately in position with the troughs of the other a small resultant system is formed, and the resistance is comparatively low. On the other hand, if two crests coincide, the resultant system is large, and excessive resistance is experienced.

It follows that residuary resistance depends separately upon three features :—

1. The size of ship.
2. The length of ship in relation to the speed.
3. The form or shape of ship.

A general account of the influence of these three features is appended, prior to giving the methods used in practice for powering ships.

EFFECT OF SIZE.

Froude's Law of Comparison.

If the linear dimensions of a vessel be l times those of a model (or another exactly similar vessel), and the resistance of the latter at speeds V_1, V_2, V_3, . . . be R_1, R_2, R_3 . . . , then at the corresponding speeds $V_1\sqrt{l}$, $V_2\sqrt{l}$, $V_3\sqrt{l}$, . . . of the former the resistances will be $R_1 l^3$, $R_2 l^3$, $R_3 l^3$. Or equally, if H_1, H_2, H_3 be the powers expended on the model, those for the ship at the corresponding speeds will be $H_1 l^{7/2}$, $H_2 l^{7/2}$, $H_3 l^{7/2}$, . . .

So that in order to compare the resistance or power of a model with that of a ship, the model must be run at the 'corresponding' speed which varies as the square root of the dimensions. If the model be constructed to a scale of $\frac{1}{4}$ inch to 1 foot, or $\frac{1}{48}$, the speed at which it must run in order to compare with a ship at V knots is $\frac{V}{\sqrt{48}}$

This law is exactly true for residuary resistance only. It is approximately true for frictional resistance, and consequently for total resistance, when the ships compared are not greatly different in dimensions. When comparing two ships of quite different dimensions, the frictional resistance must be estimated separately and deducted from the total, or some equivalent method of correction should be adopted.

Separate Variation of Displacement and Speed.

The E.H.P. (H) can be expressed in the form $H = KW^m V^n$ where W = displacement, V = speed, K = a coefficient. The indices m and n are not constant, but vary at different speeds; over a short range of speeds they are, however, practically constant; n is slightly less than 3 at low speeds; at moderate speeds it increases to 5 or 6, at very high speeds it again becomes approximately 3. m and n are connected in similar ships by the relation $6m + n = 7$.

At low or very high speeds, when $n = 3$, $m = \frac{2}{3}$; hence the power then varies as the square of the dimensions approximately.

At certain intermediate speeds, when $n = 5$, $m = \frac{1}{3}$; hence, the power varies directly as the linear dimensions.

It is above assumed that when the displacement varies a corresponding variation takes place in the length. The results do not in consequence apply to the same ship at

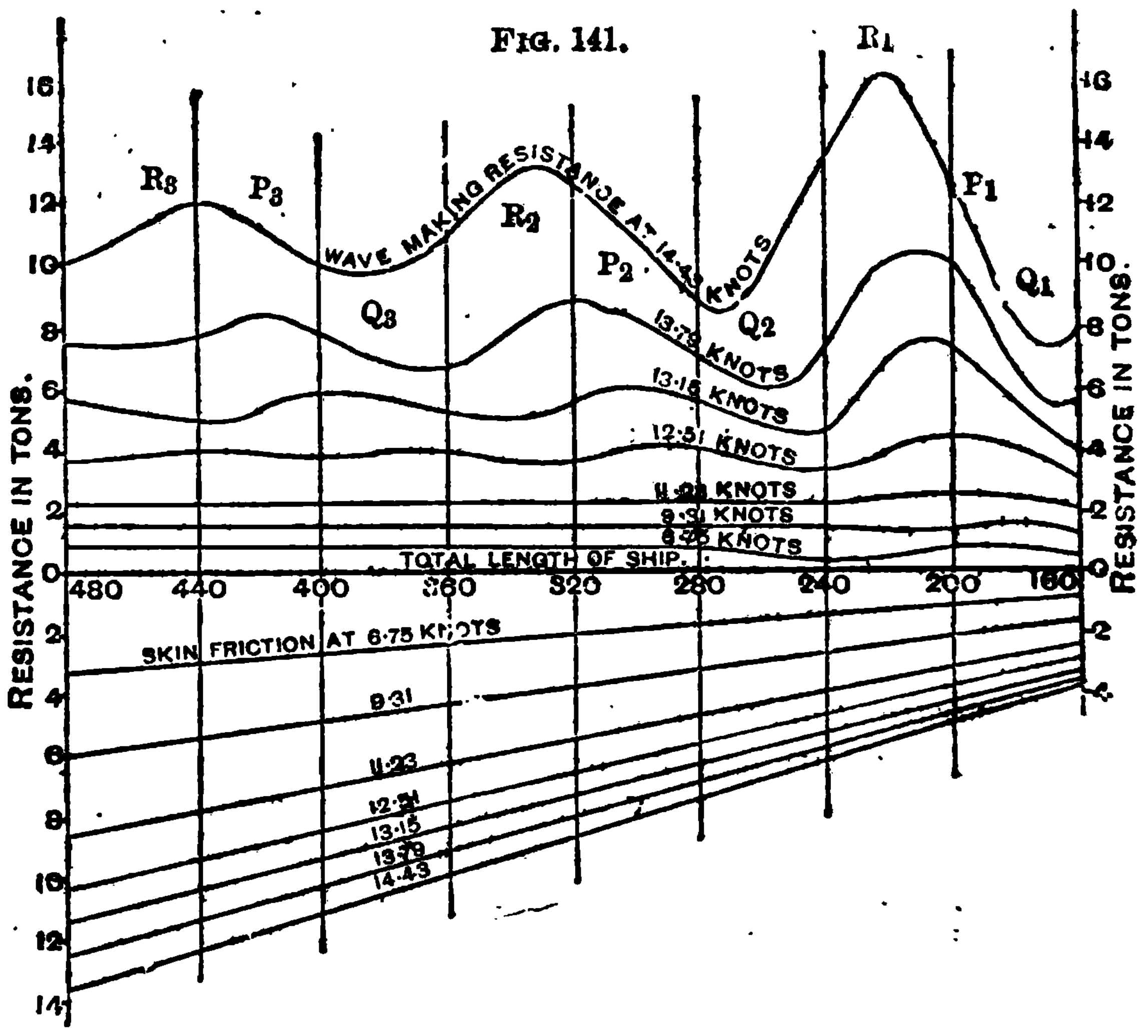
different draughts. It is found that m is then very nearly unity, so that the following rule is obtained :—

The change of power due to a moderate variation of draught in a ship without change of speed can be determined approximately by assuming the power to vary directly as the displacement.

Effect of Change of Trim.

In smooth water the effect of moderate change of trim on the resistance of a well-designed ship is very small. At speeds that are very high in comparison with the dimensions, e.g. in high speed motor-boats, considerable change of trim by the stern or 'squatting' is apt to take place. This, apart from its effect on the seaworthiness, increases the resistance. It is prevented by the broad, flat stern usual in such cases; this, however, increases the resistance at low speeds owing to the additional wetted surface.

FIG. 141.



RELATION BETWEEN SPEED AND LENGTH.

This was originally investigated by W. Froude (Trans. Inst.N.A., 1877). By varying the length of parallel middle body he obtained the results shown in fig. 141 for a series of ships having identical entrance and run. As would be anticipated, the frictional resistance, shown below the base-line, increases steadily as the length gets greater; but the wave-making resistance fluctuates considerably at the higher speeds owing to interference between the bow and stern transverse wave systems. At a particular speed, certain

lengths, shown at Q_1, Q_2, and Q_3, are favourable, other lengths, indicated at R_1, R_2, R_3, are unfavourable to propulsion. Intermediate between these points are others—P_1, P_2, P_3—at which an increase of length is beneficial, but a decrease of length is detrimental. Froude found further that at different speeds the lengths should follow the law of comparison, i.e. should vary as (speed)^2. The fluctuations are of small importance at small speeds or for great lengths.

These results have been confirmed and extended by Mr. G. S. Baker, who has deduced simple formulæ applicable to all vessels of ordinary form (Trans. Inst. N.A., 1913 and 1914). On plotting a coefficient representing the resistance of ships on a base of speed, 'humps' were obtained at certain speeds. These speeds correspond exactly to the midway points P_1, P_2, P_3, shown above on the resistance-length curves. At speeds somewhat greater than these, or equally with lengths somewhat lessened (at points Q_1, Q_2, Q_3) the resistances are comparatively low. At rather lower speeds however, or for rather greater lengths, the resistance is comparatively large. It was found that the position of the humps depended upon the coefficient P, determined by the formula

$P = \cdot 746 \dfrac{V}{\sqrt{\gamma L}}$ where V is in knots, L in feet, and γ is the prismatic coefficient (see p. 93).

In vessels of usual type, the points P_1, P_2, P_3, i.e. the intermediate points in the resistance length curves (fig. 141), or the humps on the resistance speed curves, occur when $P = 1, \dfrac{1}{\sqrt{2}}, \dfrac{1}{\sqrt{3}}$, etc.

Hence, for favourable propulsion, P is somewhat greater, so that $V^2/\gamma L$ is approximately 2·39, 1·03, or 0·65.

This gives the following suitable lengths and prismatic coefficients for various speeds :—

Speeds in knots.	Approximate favourable water-line lengths in feet for various prismatic coefficients (γ).								
	$\gamma = \cdot 6$			$\gamma = \cdot 7$			$\gamma = \cdot 8$		
	$P = \sqrt{\frac{4}{3}}$	$= \sqrt{\frac{4}{7}}$	$= \sqrt{\frac{4}{11}}$	$= \sqrt{\frac{4}{3}}$	$= \sqrt{\frac{4}{7}}$	$= \sqrt{\frac{4}{11}}$	$= \sqrt{\frac{4}{3}}$	$= \sqrt{\frac{4}{7}}$	$= \sqrt{\frac{4}{11}}$
33	760	—	—	650	—	—	570	—	—
30	625	—	—	540	—	—	470	—	—
27	510	—	—	435	—	—	380	890	—
24	400	940	—	345	800	—	300	700	—
21	305	720	—	260	600	—	230	540	—
18	225	525	820	190	440	700	170	400	620
15	155	365	570	135	320	500	120	280	440
12	100	235	370	86	200	320	75	175	275
9	56	130	200	48	110	175	42	100	150

Lengths midway between those given in the table will generally give bad propulsive results. It should be noted that, generally speaking, in high speed ships, increase of length is beneficial to propulsion; but when practicable γ should also be varied so as to comply with the relation in the preceding table and formulæ.

With extremely high relative speeds, e.g. in destroyers and steam pinnaces, another hump occurred in the resistance speed curve when $P = 1{\cdot}5$. For a prismatic coefficient of ·6, this gives the following lengths and speeds:—

Speed in knots . .	36	33	30	27	24	21	18	15
Length in feet . .	530	450	370	300	240	180	130	90

Lengths equal to, or rather greater than, the above are unfavourable; but lengths smaller than these are fairly favourable, comparatively speaking, although the speeds are then very high compared with the size of vessel.

Length of Entrance.

In the paper above referred to, Mr. Baker also stated that in some cases a hump occurred in the speed curve depending on the length of entrance (L_E) alone. This may be of importance in full ships; and unfavourable conditions then result when $V = 1{\cdot}095\sqrt{L_E}$, approximately.

Effect of Form and Proportions.

No rules of universal application can be formulated. The following brief summary represents conclusions that are in general sound, but to which there are many exceptions.

1. *Shape and proportions of transverse sections.*—If the area of the midship section is kept unaltered, change in the ratio of beam to draught affects both skin and residuary resistance to about the same extent. The deep and narrow ship is usually easier to drive, but the difference is hardly appreciable when the beam-draught ratio is less than about 3·5. From some observations by Colonel Rota (Trans. Inst. N.A., 1905) it appears that at ordinary speeds (up to $V/\sqrt{L} = 1{\cdot}4$) the total resistance for ratio 7 is some 15% more than for the most favourable ratio (about 3 or less).

Variation in shape of midship section, apart from variation of area and proportions, has very slight influence on the resistance.

At the ends the shape of transverse section is not of great importance at low speeds, but at moderate speeds ($V/\sqrt{L}$ ·8 to 1·2) U sections forward and V or hollow sections aft should be adopted.

2. *Relation between length and displacement.*—This is represented by the ratio $L/W^{\frac{1}{3}}$ (Froude), or $W/(\frac{1}{100}L)^3$ (Taylor). Unless the speed is very low the resistance per ton of

a ship having large beam and draught is much greater than that of a ship having small lateral dimensions with the same length, speed, and coefficients of fineness. The length-displacement ratio is thus one of the most important factors affecting the resistance at high speeds. In practice, however, the length is determined by a variety of considerations. In large warships it is often virtually fixed from the lengths of the internal compartments of the ship. In fast ships due attention must be given to the relation between length and speed as well as to that between length and displacement; the standard results of Froude and Taylor (see p. 179) can be used in such cases as a guide. It must be remembered that in all cases additional length involves increased frictional resistance; so that a compromise between conflicting considerations has generally to be made.

3. *Prismatic coefficient and curve of areas of sections.*—Mr. G. S. Baker (Trans. I.N.A., 1914) has recorded the results of a systematic series of experiments made on models of a ship $400' \times 52\frac{1}{2}' \times 23{\cdot}2$ of mercantile form. There were three groups of trials, designated F, G, H, having lengths of parallel body of 41·8′, 120′, and 200 respectively. The midship section coefficient was ·98, there being no rise of floor.

The entrance and run were varied for each group in the following manner:—

No. of experiment	Prismatic coefficients (γ)					Remarks
	Entrance	Run	Whole ship, group F	Whole ship, group G	Whole ship, group H	
1	·72*		·712	·775	·85	—
2	·672	All	·691	·758	·828	Straight line bow
3	·672		·691	·758	·828	Medium ,, ,,
4	·672	·638	·691	·758	·828	Hollow ,, ,,
5	·625		·67	·741	·816	—
6		·578	·664	·737	·812	—
7	All	·638	·691	·758	·828	Straight line stern
8		·638	·691	·758	·828	Medium ,, ,,
9	·672	·638	·691	·758	·828	Hollow ,, ,,
10		·70	·719	·780	·843	—

* ·764 for H.

The mean displacements were 9,400, 10,300, 11,260 tons in the three groups. The results were plotted on a base of P, or $\dfrac{V}{1{\cdot}34\sqrt{\gamma L}}$, where γ is the prismatic coefficient of the whole ship. The conclusions as regards the total resistance were briefly as follows:—

Fineness of entrance.—Set F. 5 better than 3 at all speeds. 3 better than 1 when P is more than ·6. Highest economical value of P is ·75.

Set G. 5 better than 3 when P exceeds ·53. 3 better than 1 when P exceeds ·57. Highest economical value of P is ·61.

Set H. 5 better than 3 when P exceeds ·45. 3 better than 1 when P exceeds ·375. Highest economical value of P is ·46.

Shape of entrance.—Set F. The medium bow (8) best over the useful range of speeds; straight best and hollow worst when P exceeded ·75.

Set G. Hollow bad. Medium best for P between ·53 and ·62. Straight best at higher speeds.

Set H. Straight best especially when P is above ·45.

Fineness of run.—Set F. 10 best when P exceeds ·65. 8 and 6 about equal.

Set G. 10 always bad. 6 slightly better than 8 when P exceeds ·55.

Set H. 10 causes serious eddy-making. 6 superior to 8.

Shape of run.—Set F. The straight (7) best up to P = ·7. The hollow slightly better at higher speeds.

Set G. Straight and medium about equal. Hollow inferior.

Set H. Straight best. Any hollow causes eddy-making.

Finally, the effect of introducing various lengths of parallel middle body was investigated. For the mean curves (Nos. 3 or 8) it was found that when this length was 42 feet (the total length being 442 feet) the propulsion was more favourable, reckoned on the basis of C (p. 177), than for greater lengths, particularly at high speeds, except when P was less than ·38, when total length of 520′ was superior. At all speeds a 600′ length (parallel body 200′) was inferior.

In regard to cruiser and other forms suitable for higher speeds than the above types, Mr. R. E. Froude states that except in extreme cases where serious eddy-making might be introduced, the resistance of a form is dependent principally on—

1. The extreme beam.
2. The curve of sectional areas.
3. The shape of the waterline forward.

1 and 3 have been considered. Two of the main features of the curve of sectional areas which affect resistances are—

(*a*) The prismatic coefficient which is proportional to the area of this curve, and equal to its mean ordinate divided by area of midship section; and

(*b*) The distribution of this area fore and aft.

(*a*) The influence of prismatic coefficient for ships of good form is shown in Mr. D. W. Taylor's results.* For speeds up to $V/\sqrt{L}=1$, this coefficient should be low. For higher speeds, there is a certain coefficient which is associated with the minimum residuary resistance per ton; thus:—

$V/\sqrt{L}$	1·1	1·25	1·50 and above.
Best prismatic coefficient about	·57	·60	·65

Broad ships require rather higher, and narrow ships rather lower, coefficients than those given. At the higher speeds a large variation can be made from the coefficient given without appreciable loss.

(*b*) Having decided upon the prismatic coefficient suitable to the particular speed, there are certain general principles to be followed in fixing the shape of the curve of sectional areas.

Generally speaking, the fore-body should be finer than the after-body. The section of maximum area and the centre of gravity of the curve of areas should be slightly abaft the middle of length.

The curve should be smooth, the variation in area of the sections being as gentle and gradual as possible. Any abrupt change in sectional area tends to produce increased resistance, and this is particularly true of the shoulders of the curve in the fore-body. The buttocks of the after-body can, however, be made relatively abrupt without detriment, provided the curve is smooth.

Resistance is generally more sensitive to variation of the fore- than the after-body, and perhaps particularly to variations at the ends of the fore-body.

At values of $\frac{V}{\sqrt{L}}$ below ·6 where a relatively small proportion of the total resistance is due to wave resistance, resistance is not sensitive to slight variation of the curves, but it is almost as necessary to obtain a curve of areas which will give a minimum resistance per ton of carrying power of the ship at these low speeds as at higher speeds.

For value of $\frac{V}{\sqrt{L}}$ ·7 to 1·2 the forward half of the curve of areas in the fore-body should be decidedly convex to the base-line, thus tending to become tangential to the base-line; the ending of the curve may, however, be made abrupt without affecting the resistance adversely.

Mr. Froude (Trans. I.N.A., 1905) showed that for cruisers within these limits of speed $\frac{V}{\sqrt{L}}$ ·7 to 1·2, rather hollow bow lines were distinctly preferable to straight ones.

* *The Speed and Power of Ships*, by D. W. Taylor (Chapman & Hall).

For still higher values of $\frac{V}{\sqrt{L}}$ the fore end of the curve of the fore-body may be straightened with advantage as the value increases until it may even be concave to the base-line.

From the above it will be seen that a curve of areas which may suit one set of speed conditions will not be at all suitable for another. It is therefore very desirable to adhere as closely as possible to the form—particularly to the forward portion—of a ship or model that has been found successful. If it is desired to increase the displacement without seriously affecting resistance it will generally be found that it can be added at the buttocks of the after-body curve of areas, provided the general smoothness of the curve is still maintained.

Methods of estimating Horse-power.

1. *By Model Experiments.*

This is the only reliable method of estimating the power required in a new design. It is advantageous and economical in two ways: (*a*) a smaller margin can be allowed on the estimated power, since the only uncertainty lies in the correct prediction of the propulsive coefficient; (*b*) the effects of varying the lines or proportions of the ship are readily investigated; important propulsive economies are thus frequently effected at a trifling cost.

As stated on p. 169, the resistance of the ship is reduced from that of the model, by means of the law of comparison, which is applied to the residuary resistance alone; the frictional resistance of both ship and model is estimated separately by a formula. By multiplying the fresh-water tank resistance by $\frac{64}{62 \cdot 5}$, allowance is made for the difference of density between fresh and salt water.

The results are conveniently recorded by means of the 'constant' system of notation devised by Mr. R. E. Froude (Trans. I.N.A., 1888 and 1892).

The method may be described as follows:—The proportions, and to some extent the lines, of the hull are characterized by numerical values and diagrams, representing not absolute measurements of hull, but measurements stated in terms of a unit-dimension proportional to the cube root of displacement. The performance and proportions of the ship are represented by 'constants', designated as follows:—

Let L, B, D = principal dimensions in feet.
W = displacement in tons.
S = wetted surface in square feet.
R = resistance in tons (salt water).
V = speed in knots.

$$\text{Then speed constant } K = \frac{V}{W^{\frac{1}{6}}} \times \cdot 5834.$$

$$\text{Resistance constant } C = \frac{R}{W^{\frac{2}{3}}V^2} \times 2938.$$

$$= \frac{\text{E.H.P.}}{W^{\frac{2}{3}}V^3} \times 427 \cdot 1.$$

$$\text{Length-speed constant } L = \frac{V}{\sqrt{L}} \times 1 \cdot 0552.$$

$$= \frac{K}{\sqrt{M}}$$

$$\text{Length constant } M^* = \frac{L}{W^{\frac{1}{3}}} \times \cdot 3057.$$

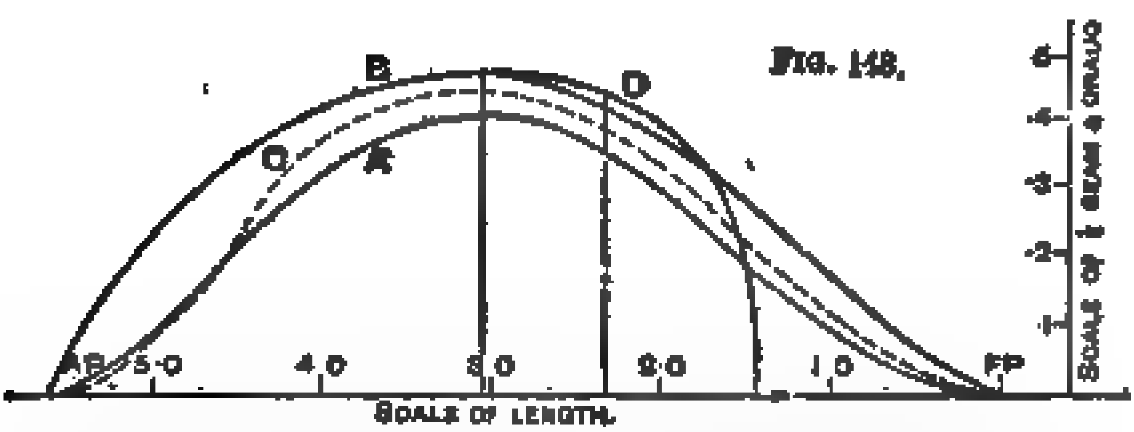
$$\text{Breadth or draught constant } B \text{ or } D = \frac{\cdot 3057}{W^{\frac{1}{3}}} \times (\text{B or D}).$$

$$\text{Skin constant } S = \frac{S}{W^{\frac{2}{3}}} \times \cdot 09346.$$

FIG. 142.

CONSTANT CURVE (CORRECTED FOR SKIN FRICTION FOR SHIP 300 FT. LONG.)

}†



A, mean water-line, viz. curve of ⅘ areas ÷ mean draught. B, load water-line. C, water-line at half mean draught. D, greatest section.

The shape and proportions of the hull are indicated in fig. 143. The readings of the lines and figures given denote, not absolute linear dimensions, but the ratios of these dimensions to the linear unit $W^{\frac{1}{3}}$, as exemplified in the above constants.

Owing to the law for skin friction resistance being different from that for residuary resistance, the constants (which are

* If θ represent Taylor's length-displacement coefficient $(W/(\frac{1}{100}L)^3)$, then $M^3\theta = 28570$ or $M \times \sqrt[3]{\theta} = 30 \cdot 57$.

† Correction curves for various length of ship. Ordinates downwards from 300 feet line to be added to, and upwards to be deducted from, the C readings of the constant curve.

based on the law of comparison) will need correction as the size of ship varies.

To make the correction, let small letters denote model, and large, ship; the ratio of linear dimensions being n. Let dashes refer to that part of resistance which is caused by friction only. Let F, f, be coefficients of friction for ship and model.

$$C' = \frac{FSV^{1\cdot 825}}{WSV^2} \times 2938 = \text{constant} \times FSV^{-\cdot 175} = \text{constant} \times$$

$$SL^{-\cdot 175} \times FL^{-\cdot 0875}.$$

Similarly, $c' = \text{constant} \times SL^{-\cdot 175} \times fl^{-\cdot 0875}$.

Hence $c - C = c' - C'$, (for that part of c which is due to residuary resistance does not alter with dimensions), $= SL^{-\cdot 175} \times (o - O)$ where the 'o' coefficients depend upon the friction and length. Typical correction curves are shown in fig. 142.

For a smooth surface, O can be found from the following table :—

Table of Values of O for Various Lengths.

Length in feet	Value of O	Length in feet	Value of O	Length in feet	Value of O	Length in feet	Value of O	Length in feet	Value of O
8	·14090	20	·11470	60	·09380	160	·08219	450	·07812
9	·13784	25	·10976	70	·09164	180	·08108	500	·07219
10	·13409	30	·10590	80	·08987	200	·08012	550	·07132
12	·12853	35	·10282	90	·08840	250	·07814	600	·07051
14	·12406	40	·10048	100	·08716	300	·07655		
16	·12036	45	·09839	120	·08511	350	·07525		
18	·11727	50	·09664	140	·08351	400	·07412		

FIG. 144.

Fig. 144 shows the variation of O for different values of M, and also through a limited range of beam : draught ratios. Such a diagram, when interpreted by appropriate scales, is

in effect a diagram showing E.H.P. at a certain speed, for all the forms reduced to a common displacement, plotted to length of hull.

2. *By Curves obtained from Methodical Experiments.*

Among the methodical experiments that have been carried out are the following :—

(*a*) By Mr. R. E. Froude (Trans. I.N.A., 1904).—The results are also given in a different form in article 'Shipbuilding' in *Encyclopædia Britannica,* 10th edition, by Sir Philip Watts, K.C.B. The parent ship is of cruiser form $350' \times 57' \times 22'$; displacement 6,100 tons ; block coeff. ·4865 ; midship section coeff. ·8775 ; prism. coeff. ·5385 fore-body, ·570 after-body, ·555 mean. The cross sections were also varied, so that for the same length the displacement varied from 2,500 to 10,500 tons ; or M varied from 7·884 to 4·886. Two ratios of beam to draught 57 : 22 and 66 : 19 were tried. The speed was altered so that K varied from 2 to 4·8. Finally, the parent form was modified so that on about the same displacement the length was reduced in steps from 350′ to 310′, increasing the prismatic coefficient from ·555 to ·618.

(*b*) By Mr. D. W. Taylor (*Speed and Power of Ships,* Chapman & Hall).—The prismatic coefficient varies from ·48 to ·80, so that the forms vary over a very wide range of types. Two ratios of beam to draught 2·25 and 3·75 were tried. The length-displacement coefficient $(W/(\frac{1}{100}L)^3)$ varied from 20 to 160, so that M varies from 11·3 to 5·6. The midship section coefficient was ·926. The ratio $V/\sqrt{L}$ varied from ·6 to 2·0.

(*c*) By Mr. G. S. Baker (Trans. I.N.A., 1913 and 1914). —The 1914 set are described on p. 173. The 1913 set consisted of five groups, each consisting of four or five models having the ratio length entrance : length run varying from ·55 or more to nearly 1·7. The ratio breadth : draught was 2·25. The prismatic coefficient varied from ·60 to ·84, chiefly by altering the proportion of middle body. The length was about eight times the beam in all cases. K varied from ·9 to 3·0. The variations of resistance due to change in the contour of bow and stern were also investigated.

(*d*) By Professor Sadler (Trans. American I.N.A., etc.).— These have reference mainly to the effect of varying the length of parallel middle body at different speeds. Length was eight times the breadth ; but the breadth-draught ratio varied from 3·0 to 2·143, and the prismatic coefficient from ·734 to ·76. $V/\sqrt{L}$ varied from ·2 to ·9. Other variations in form were also tried.

(*e*) By Sir John Biles (*Design and Construction of Ships,* vol. ii, Griffin & Co.).—Particulars of the resistances of thirteen vessels of widely differing types are given. The results are presented in a form very convenient for practical application to new designs.

Of these results, those by Mr. D. W. Taylor cover by far the widest range, although Mr. Froude's series include very many useful cruiser and battleship forms. The application of the results to the powering of ships is in each case easy. The data will be found useful both for powering and for determining suitable forms for such ships as come within the ranges dealt with.

For fishing-boats and fine-lined commercial motor-vessels, a table of approximate B.H.P. and speeds is given by Mr. Linton Hope, Trans. I.N.A., 1910.

3. *By the Admiralty Coefficient.*

The ratio $\dfrac{W^{\frac{2}{3}} V^3}{\text{I.H.P.}}$, or $\dfrac{W^{\frac{2}{3}} V^3}{\text{S.H.P.}}$ for ships driven by turbines, is termed the Admiralty coefficient. It is connected with Froude's resistance "constant" C by the relation $\lambda C = 427 \cdot 1 \mu$, or $\lambda = 427 \cdot 1 \mu / C$; where λ = Admiralty coefficient, μ = propulsive coefficient (*v.* p. 161).

This coefficient is not constant, even for the same ship at different speeds. Its value depends on the efficiency of propulsion, the form, and the speed of the ship. For similar ships at corresponding speeds it is constant provided that the means of propulsion are also similar, and that the actual dimensions are not so greatly different as to necessitate an appreciable frictional correction. For similar ships at very low speeds it is almost constant.

It is to be noted that a high Admiralty coefficient indicates comparatively low power, i.e. economical or favourable propulsion.

The factors on which the Admiralty coefficient *principally* depend are, in order of importance :—

(*a*) Type of ship, which generally includes mode of propulsion, affecting μ.

(*b*) Speed-length ratio – $V/\sqrt{L}$.

(*c*) Length-displacement ratio **M** or $\dfrac{L}{W^{\frac{1}{3}}} \times \cdot 3057$ in Froude's notation.

(*d*) Prismatic coefficient.

(*e*) Form including **B**, **D**, shape of sectional area curve, shape of water-line forward.

(*f*) Absolute size. Small boats or ships have relatively low coefficients owing partly to the relatively greater skin friction.

(*e*) and (*f*) are to some extent included in (*a*).

The data in the following table are obtained from actual trials of ships; they can be used for predicting the Admiralty coefficient, and thus the power of a new ship, provided it resembles fairly closely one or more of the ships in the table, can be estimated. The accuracy of the prediction and the reliability of the method depend entirely on this approximate similarity between ships and engines; when this is not fairly good the method is quite untrustworthy. If the propulsive coefficients of the two ships compared are probably not the same, their variation should be allowed for.

No attempt is made in the table to cover all forms and proportions of frequent practical occurrence; a few ships of each of the leading types are dealt with. The arrangement of the data that is adopted in the table will generally be found convenient for recording the results of the trials of ships in a form that facilitates their utilization for approximately powering new designs. L = length b.p.; W = displacement in tons; V = speed in knots; B/D = ratio of breadth to mean draught; β = block coefficient; R, T = reciprocating or turbine.

The prismatic coefficient can usually be inferred from β and the type of ship; in some cases the midship section coefficient is added.

ADMIRALTY COEFFICIENTS OF VARIOUS VESSELS.

Ship.	L	W	V	$V/\sqrt{L}$	$\frac{W}{(L/100)^3}$	$\frac{B}{D}$	β	H.P.	R. T.	No. of Screws.	Admiralty C…
Cargo . . .	410	1180(	14·15	·70	230	2·0	·75	5000	R	2	29
Passenger boat	470	1320(	16·1	·74	120	2·5	·64	7900	R&T	4	29
" . .	470	1320(	14·5	·66	120	2·5	·64	5400	R	4	31
" . .	155	860	10·1	·85	230	1·7	·61	241	R	1	43
" . .	170	1060	11·15	·85	215	2·1	·60	437	R	1	33
" . .	247	3070	10·5	·68	205	1·9	·70	818	R	1	30
Oil tank . .	470	17200	14·2	·65	165	2·0	·81	5000	R	1	32
Motor cargo boat	360	9500	11	·58	200	2·2	·78	2160	R	2	27
" "	360	9500	8	·42	200	2·2	·78	850	R	2	27
Liner . . .	760	37080	25·6	·93	85	2·7	·60	76000	T	4	24
" . . .	760	37080	23·7	·86	85	2·7	·60	51300	T	4	28
" . . .	760	37080	20·4	·74	85	2·7	·60	29500	T	4	31
" . . .	760	37080	15·8	·57	85	2·7	·60	13400	T	4	32
Oil tank . . .	402	15700	12·5	·62	240	2·0	·78	8300	R	1	31
Salvage steamer	186	1000	12·3	·90	156	2·5	·57	690	R	1	27
Ore carrier . .	320	5430	13·25	·74	166	2·3	·78	2365	R	1	30
Cargo . . .	279	4780	12·3	·74	218	2·0	·76	1577	R	1	33
River . . .	195	685	10·7	·76	92	9·5	·81	834	R	2	10
Passenger . .	420	9600	17·8	·87	130	2·0	·64	6780	R	1	37
Training ship .	270	4370	10	·61	222	2·2	·64	932	R	2	28
Steam collier .	280	4188	12	·72	191	2·2	·79	1880	R	1	21
Channel steamer	260	2110	15	·93	120	2·9	·63	1640	R	2	33
Cable steamer .	243	2526	13	·83	177	2·2	·70	1790	R	2	22
Cargo and passenger .	180	1287	12·3	·92	212	2·1	·65	770	R	1	27
River . . .	310	2460	15·4	·87	82	4·9	·54	3076	R	2	21
Cargo and passenger .	300	4268	15	·87	158	2·3	·68	2811	R	1	31
"	465	15970	16·4	·76	160	2·1	·75	7520	R	2	37
Dredger . . .	105	299	6·5	·63	258	4·5	·63	100	R	1	12
Trawler . . .	105	300	10·15	1·10	275	2·2	·48	406	R	1	11
Liner . . .	550	21660	20·6	·88	130	2·0	·69	20000	T	3	34
Ferry (geared turbine) : .	250	865	18	1·14	55	6·3	·53	2500	T	2	21
"	250	865	16	1·01	55	6·3	·53	1520	T	2	24
"	250	865	13	·82	55	6·3	·53	440	T	2	45
"	250	865	10	·63	55	6·3	·53	200	T	2	45

Admiralty Coefficients (Tugs, Small Craft, etc.).

Ship.	L	W	V	$V/\sqrt{L}$	$\frac{W}{(L/100)^3}$	$\frac{B}{D}$	β	H.P.	Mid. Sec. Coefficient.	No. of Screws.	Admiralty Coefficient.
Tug	140	440	11·75	1·00	160	2·7	·52	840	·80	2	112
,, ...	120	235	12·25	1·12	136	2·7	·46	590	·73	2	126
,, ...	110	230	11·0	1·05	173	2·7	·52	460	·80	1	100
,, ...	140	620	12·1	1·02	226	2·5	·57	1120	—	2	114
,, ...	100	240	10·5	1·05	240	2·2	·46	410	—	1	109
,, ...	90	230	10·25	1·08	182	2·2	·54	420	·85	1	75
,, ...	80	120	9·1	1·82	234	2·7	·54	240	·93	1	72
,, ...	71½	110	10·6	1·25	342	2·2	·52	330	—	1	82
,, ...	70	115	10·4	1·24	335	2·4	·48	350	—	1	76
,, ...	65	90	10·2	1·26	328	2·2	·49	190	·88	1	112
,, ...	60	57	8·1	1·05	265	2·6	·50	106	—	1	74
,, ...	45	29	8·25	1·23	318	2·8	·55	60	·87	1	93
,, ...	40	24	8·2	1·67	375	2·2	·51	65	·83	1	68
Passenger boat	135	340	11·1	·96	138	3·8	·64	547	·91	2	126
,,	130	260	10·5	·92	118	4·2	·51	350	—	2	135
,, .	175	560	10·1	·76	104	4·8	·64	520	—	2	134
Yacht	160	4[illegible]6	11·8	·93	114	2·2	·39	459	·65	1	220
,, ...	140	278	11·6	·98	101	2·5	·37	375	·62	1	182
Grab hopper dredger . .	140	920	8·5	·72	335	2·6	·72	498	—	1	117
,,	100	280	7·1	·71	280	4·8	·77	160	—	1	100
Hopper barge .	125	420	9·0	·72	215	3·2	·65	200	·95	1	181
,,	147	675	8·5	·70	212	2·7	·66	330	—	1	124
Harbour launch	100	150	10·7	1·07	150	2·6	·48	260	—	1	132
Passenger paddle steamer .	165	250	13·5	1·1	561	4·2	·50	5[illegible]0	·80	—	172
,,	205	450	16·7	1·17	52	3·6	·49	15[illegible]0	·85	—	176
,,	120	76	10·5	·96	44	6·4	·56	125	·86	—	167
,,	170	270	13·5	·80	55	3·8	·47	580	—	—	180
,,	130	130	11·5	·88	59	6·5	·71	350	—	—	109
,,	220	620	8·0	·54	58	7·2	·85	310	—	—	119
,,	110	160	11·3	1·08	120	4·4	·64	330	—	—	129
Stern wheeler .	76	393	8·3	·95	90	12·7	·72	113	—	—	58
,,	107	150	9·7	·94	122	10·0	·78	260	—	—	99
,,	135	177	8·4	·72	72	13·5	·85	266	—	—	70
,,	120	150	8·8	·80	87	12·8	·86	253	—	—	76
,,	83	61	8·4	·92	107	10·0	·77	186	—	—	50
Launch . . .	45	7	9·5	1·41	77	3·0	·20	45	·40	1	69
,, . . .	56	11	15·0	2·00	65	3·0	·22	150	·41	1	109
,, . . .	50	12	9·5	1·34	96	2·9	·24	43	·38	1	100
,, . . .	55	23	8·5	1·15	138	3·8	·38	45	—	1	120
,, . . .	60	40	11·1	1·43	185	2·2	·42	150	—	1	107
Tunnel steamer	67	25	8·0	·93	76	9·8	·69	65	—	2	64
,,	160	200	10·25	·81	49	15·0	·73	325	—	2	76
,,	140	152	13·7	1·15	56	7·0	·60	540	—	2	135
Tunnel lifeboat	57	37	10·23	1·36	200	3·6	·52	182	—	2	65
Tunnel steamer	125	120	9·4	·84	61	9·1	·49	235	—	2	51
,,	50	12	9·0	1·27	96	4·5	·47	57	—	1	67
Tug	115	400	11·1	1·04	316	2·4	·51	1120	—	2	75
Paddle ferry .	134	2[illegible]0	11·0	·95	91	5·5	·65	516	—	—	96
Tender . . .	80	74	11·3	1·27	144	2·4	·44	205	—	2	92
Vedette boat .	100	51	18·0	1·8	51	4·6	·48	622	—	2	129

Class of Boat.	L	W	V	$V/\sqrt{L}$	$\frac{W}{(L/100)^3}$	$\frac{B}{D}$	β	B.H.P.	No. of Screws.	Admiralty Coefficient
Ketch drifter . .	65	57	8·0	·99	210	3 0	·27	60	1	12
Lugger drifter .	71	70	5·1	·62	195	3 0	·24	25	1	9
Irish ketch . .	47	23	6 7	·89	270	2·8	·30	20	1	13
Lowestoft ketch .	60	64	6 5	·80	300	2·7	·33	35	1	12
Sailing trawler .	72	114	5 2	·12	305	2·1	·34	34	1	10
Fishing boat . .	29	9	7 0	1·26	370	2·8	·33	12	1	12
„	—	—	4·5	·82	—	—	—	7	1	5
Oyster dredger .	45	21	6 0	·89	230	3 0	·29	17	1	9
Schooner . . .	153	735	7 8	·63	205	2·7	·60	190	1	19
Coaster yacht . .	71	115	7·8	·92	320	2 6	·61	40	1	27
Pilot ship . . .	64·5	64	6·0	·75	240	2·7	·30	30	1	11
Oil tank lighter . .	60	93	5 5	·71	430	4 0	·67	45	1	7
„	60	83	6 2	·81	155	11·3	·65	45	1	5
Tunnel boat . .	59	95	7 0	·91	46	15·7	·66	20	1	7
„	55	12	8 0	1·03	72	7 8	·74	83	1	8
Chain haulage tug (punt) . . .	28	49	2·5	—	220	7·8	·77	16	1	[illegible]
Chain towing eight punts (100 tons)	28	105	2·5	—	480	7·8	·77	16	1	2
Cargo and passenger	42	20	7·4	1·14	270	4 0	·46	45	1	6
Mail and passenger	94	86	10·2	1·08	130	3 5	·44	152	2	11
„	70	18	10·6	1·28	52	6 5	·36	100	1	8
„	40	5	10·6	1·63	78	5 6	·30	45	1	7
Dispatch boat . .	55	11	10 9	1·72	63	3·1	·27	60	1	10
„	55	13	14·2	1·91	78	3 0	·31	200	1	7

WARSHIPS.

Ship.	L	W	V	$V/\sqrt{L}$	$\frac{W}{(L/100)^3}$	$\frac{B}{D}$	β	H.P.	R. T.	No. of Screws.	Admiralty Coefficient
Battleship .	400	15,200	18·3	·92	237	2·8	·65	16,400	R	2	230
„	400	15,200	13·1	·66	237	2·8	·65	4,360	R	2	315
„	436	11,750	19·6	·94	142	2·9	·54	12,500	R	2	312
„	436	11,750	17·7	·85	142	2·9	·54	8,750	R	2	328
„	436	11,750	14·7	·70	142	2·9	·54	6,000	R	2	328
„	436	11,750	10·0	·48	142	2·9	·54	1,730	R	2	299
„	580	25,000	22·1	·92	128	3·2	·60	32,700	T	4	282
„	500	19,000	21·0	·94	152	3·1	·60	24,500	T	4	270
„	500	19,000	18·4	·82	152	3·1	·60	14,700	T	4	302
„	500	19,000	13·0	·58	152	3·1	·60	4,900	T	4	320
„	500	19,000	10·0	·45	152	3·1	·60	2,300	T	4	310
Cruiser .	355	5,270	21·3	1·15	118	3·0	·50	12,500	R	2	234
„	355	5,270	19·5	1·04	118	3·0	·50	8,750	R	2	236
„	355	5,270	16·7	·79	118	3·0	·50	5,000	R	2	282
„	500	14,250	24·1	1·08	114	2·7	·54	31,500	R	2	261
„	500	14,250	20·0	·90	114	2·7	·54	14,750	R	2	318
„	500	14,250	13·1	·58	114	2·7	·54	4,040	R	2	323
„	500	14,250	5·5	·10	114	2·7	·54	1,690	R	2	58
„	550	18,750	24·3	1·04	113	3·1	·58	34,400	T	4	293
„	550	18,750	22·4	·96	113	3·1	·58	25,800	T	4	307
„	550	18,750	16·4	·70	113	3·1	·58	8,600	T	4	361
„	430	5,400	26·2	1·26	68	3·2	·56	28,000	T	2	198
Destroyer	280	1,000	33·0	1·97	46	3·0	·52	15,500	T	3	231
„	270	950	27·0	1·65	48	2·9	·50	13,000	T	3	147
„	220	400	30·0	2·02	38	2·6	·41	6,400	R	2	229
„	240	775	30·9	1·29	56	3·2	·54	19,000	T	2	131

Table of Two-thirds Powers.

w	$w^{\frac{2}{3}}$	w	$w^{\frac{2}{3}}$	w	$w^{\frac{2}{3}}$
100	21·5	1,000	100	10,000	464
110	23·0	1,100	107	11,000	495
120	24·3	1,200	113	12,000	524
130	25·7	1,300	119	13,000	553
140	27·0	1,400	125	14,000	581
150	28·2	1,500	131	15,000	608
160	29·5	1,600	137	16,000	635
170	30·7	1,700	142	17,000	661
180	31·9	1,800	148	18,000	687
190	33·0	1,900	153	19,000	712
200	34·2	2,000	159	20,000	737
220	36·4	2,200	169	22,000	785
240	38·6	2,400	179	24,000	832
260	40·7	2,600	189	26,000	878
280	42·8	2,800	199	28,000	922
300	44·8	3,000	208	30,000	965
320	46·8	3,200	217	32,000	1,008
340	48·7	3,400	226	34,000	1,050
360	50·6	3,600	235	36,000	1,090
380	52·5	3,800	244	38,000	1,130
400	54·3	4,000	252	40,000	1,170
440	57·8	4,400	269	44,000	1,246
480	61·3	4,800	285	48,000	1,321
520	64·7	5,200	300	52,000	1,393
560	67·9	5,600	315	56,000	1,464
600	70·5	6,000	330	60,000	1,533
650	75·0	6,500	348	65,000	1,617
700	78·8	7,000	366	70,000	1,698
750	82·5	7,500	383	75,000	1,778
800	86·2	8,000	400	80,000	1,857
850	89·7	8,500	416	85,000	1,933
900	93·2	9,000	433	90,000	2,008
950	96·6	9,500	448	95,000	2,082

Note.—Intermediate values of $w^{\frac{2}{3}}$ can be obtained by interpolation where moderate accuracy alone is required, e.g. in connexion with the 'Admiralty coefficient' for determining the horse-power of ships. Otherwise find w in the table of cubes at the end, and read off $w^{\frac{2}{3}}$ in the "squares" column opposite.

4. *From Progressive Trials, extending the law of comparison.*

In this method it is assumed that the form and proportions are fairly similar; that the H.P. of a ship with speed constant varies as the displacement; and that the variation in propulsive coefficient can be neglected (or it may be known and allowed for afterwards).

Let the symbols W, L, and V refer to the displacement, length, and speed of the new ship, of which the power H is required. Let W_1, L_1 refer to a ship of similar type whose horse-power (H_1) over a range of speeds (V_1) have been determined by trial.

By Froude's law of comparison, the data for the old ship can be changed to $W_1 n^3$, $L_1 n$, $V_1 n^{\frac{1}{2}}$, $H_1 n^{\frac{7}{2}}$; where n is any ratio.

Choose n so that $L_1 n = L$, or $n = \dfrac{L}{L_1}$ Then select a speed V_1 in the old ship so that $V_1\sqrt{n} = V$, or $V_1 = V/\sqrt{n}$.

Read the horse-power H_1 for the old ship, corresponding to the speed V_1. Then that of the new ship is $H_1 n^{\frac{7}{2}}$. This applies, however, to displacement $W_1 n^3$, which is usually different from W. On correcting for this, we have, finally, that horse-power of new ship at speed V and displacement W $=$

$$H_1 n^{\frac{7}{2}} \times \frac{W}{W_1 n^3} = H_1 \cdot \frac{W}{W_1} \cdot \sqrt{\frac{L}{L_1}}$$

Example.—To find the S.H.P. of a ship, 25 knots speed, 800′ long, having a displacement of 36,000 tons, and generally resembling the *Lusitania*.

Here $L = 800$, $V = 25$, $W = 36{,}000$. Also for *Lusitania*, $L_1 = 760$, $W_1 = 37{,}080$.

Then $n = \dfrac{L}{L_1} = \dfrac{800}{760} = 1 \cdot 052$.

$$V_1 = V/\sqrt{n} = \frac{25}{\sqrt{1 \cdot 052}} = 24 \cdot 37.$$

From curve (fig. 145) of speed and horse-power for *Lusitania,* the corresponding power H_1 is 57,600.

Hence power for new ship under the conditions required $=$

$$57{,}600 \times \frac{36{,}000}{37{,}080}\sqrt{1 \cdot 052} = 57{,}500.$$

5. *From approximate Formulæ or Curves.*

Since it is possible to estimate the frictional resistance with fair accuracy, in ships of low or moderate speed a considerable error in the value of the residuary resistance will make only a small difference to the total resistance, which is mainly frictional. In such cases, provided the ship be sufficiently well formed aft to avoid eddy-making, an approximate formula or a simple series of curves may be used to estimate the residuary resistance.

The following data are taken from a paper by Mr. A. W. Johns, M.I.N.A. (Trans. I.N.A., 1907).

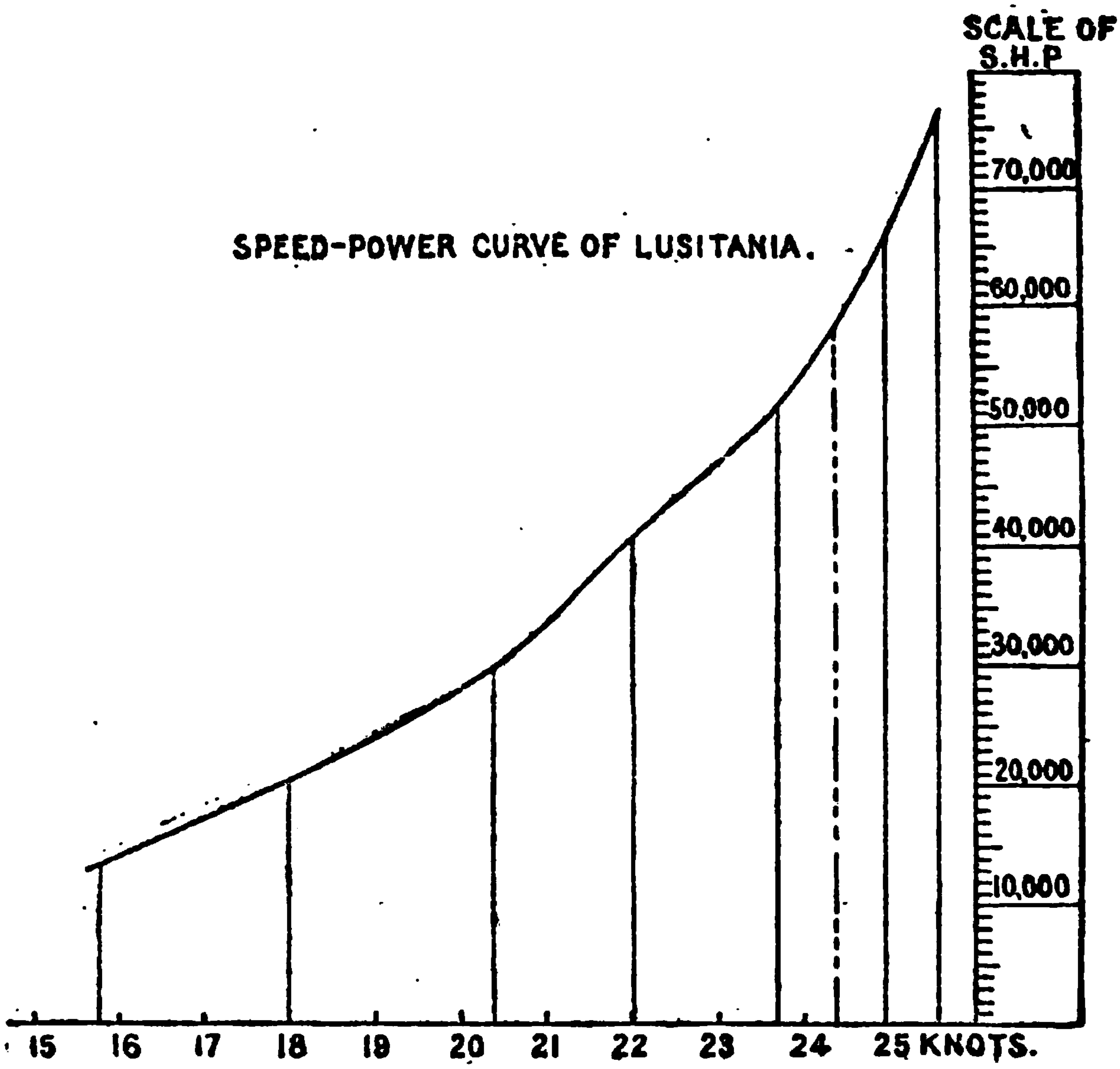
(*a*) Mr. D. W. Taylor gives the formula—

Residuary resistance in lbs. per ton $= 12{\cdot}5\,\beta V^4/L^2$; where $\beta =$ block coefficient, and L is length on water-line in feet.

(*b*) Mr. Taylor has also given the curves shown in fig. 146. It was stated that the formula is usually more accurate for low speeds (up to $V/\sqrt{L} = \cdot 9$), while the curves are preferable for higher speeds. In either case, residuary E.H.P. = resistance in lbs. per ton × wv/326.

(*c*) Mr. Johns gave the curves shown in fig. 147. These are applicable to ships having low or moderate speeds. Take L as the length between perpendiculars; and in merchant ships increase the actual prismatic coefficient by ·02 before applying it to the curves.

FIG. 145.



It is to be observed that Taylor's curves omit the prismatic coefficient, and that Johns' curves omit the relation between length and displacement. It would appear that the former curves should give better results for a ship of unusual proportions, and that the latter should be superior for a ship with unusually fine or full lines.

Example.—To find the horse-power of the ship in the example on p. 185. Assume draught 30′, L = 800; V = 25; W = 36,000.

FIG. 146.

SIDUARY RESISTANCE IN POUNDS PER TON OF DISPLACEMENT

By D. W. Taylor, Esq.

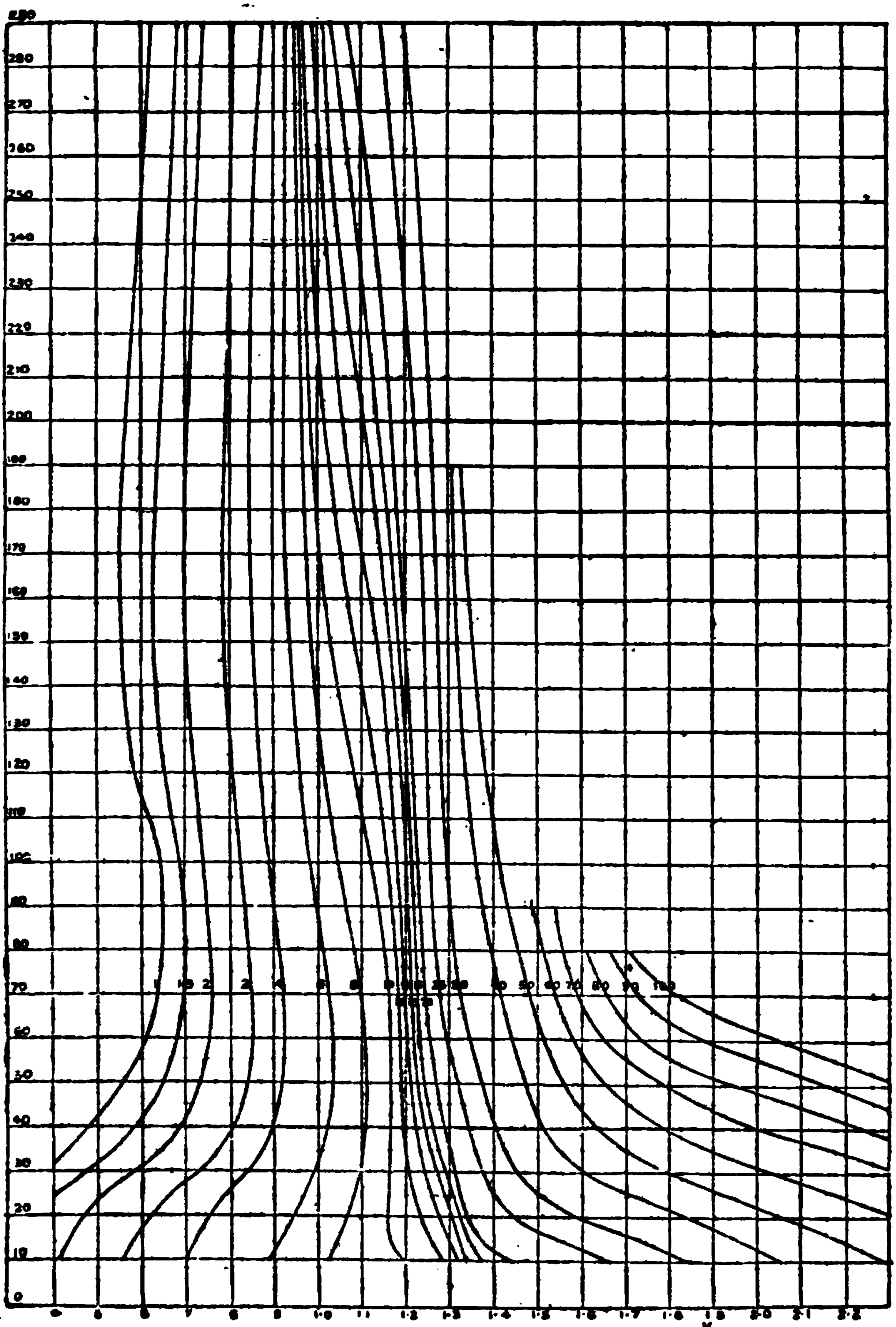
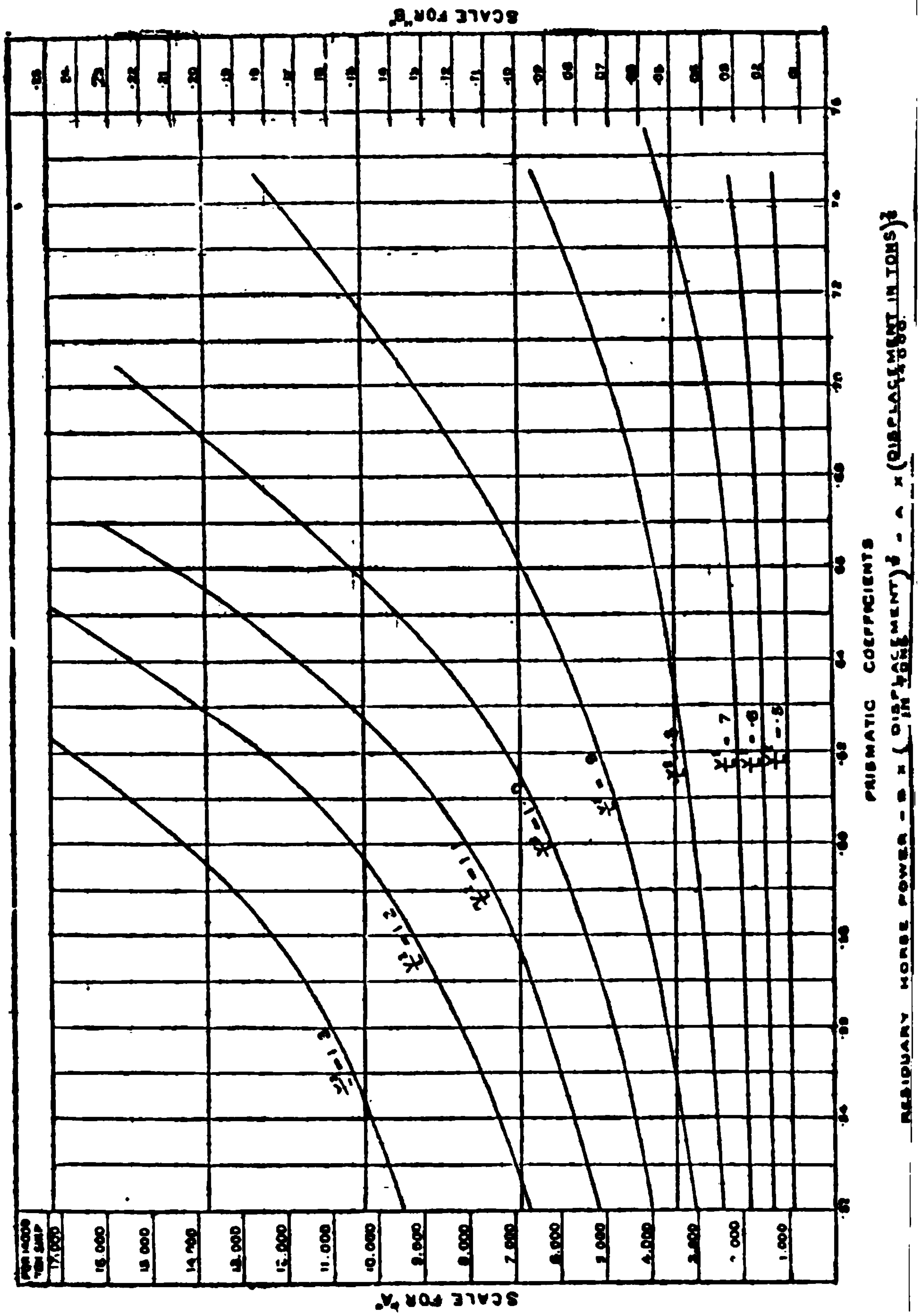


FIG. 147.

CURVES OF RESIDUARY E.H.P.

By A. W. Johns, Esq. (see p. 186).



Note.—In merchant ships increase actual prismatic coefficient by ·02 be[fore] applying it to the curves.

Wetted surface by Denny's formula $= 82800$.

From the table on p. 167 it appears that $f =$ about $\cdot 236$ for $\text{L} = 800'$. Frictional E.H.P. $= \cdot 236 \times 82800 = 19500$.

Using Taylor's curves, $\text{W}/\left(\frac{\text{L}}{100}\right)^3 = 70\cdot 3$; $\text{V}/\sqrt{\text{L}} = \cdot 885$, whence residuary resistance per ton $= 3\cdot 5$ approximately.

Residuary E.H.P. $= 3\cdot 5 \times 36000 \times 25 \div 325 = 9700$.

Alternatively using Johns' curves, prismatic coefficient $= \cdot 62 + \cdot 02 = \cdot 64$. $\text{V}^2/\text{L} = \cdot 782$. Whence residuary E.H.P. $= \cdot 047 \times (36000)^{\frac{7}{6}} = \cdot 047 \times 36000 \times \sqrt[6]{36000} = 9700$.

In this case both sets of curves are in absolute agreement.

Total E.H.P. $= 9700 + 19500 = 29200$.

Actual propulsive coefficient of *Lusitania* was ·50. Take, when estimating, a lower coefficient, say ·46, in order to allow a reasonable margin.

Hence estimated S.H.P. for new ship $= 29200 \div \cdot 46 = 63500$.

Effect of Shallow Water.

The following table gives the percentage increase (or *decrease* for figures in italics) of E.H.P. in shoal water as compared with deep water at the same speed. It applies to a destroyer form, where $\text{W}/\left(\frac{\text{L}}{100}\right)^3 = 40$; but it would serve as a rough guide in any other type of ship.

Percentage variation of Horse-power.

$\frac{\text{V}}{\sqrt{\text{L}}}$	Depth of water ÷ Length of ship.								
	·05	·1	·2	·3	·4	·5	·6	·7	·8
2·07	—	*10·0*	*9·1*	*6·0*	*3·3*	*1·9*	*1·2*	*·7*	*·5*
1·94	—	*11·4*	*9·4*	*4·5*	*1·5*	*·9*	*·7*	*·6*	*·4*
1·80	—	*10·6*	*7·0*	—	1·8	1·2	·5	·2	—
1·66	—	*7·2*	*1·2*	7·2	5·5	1·8	—	—	—
1·52	—	5	16	20	7·5	1·2	—	—	—
1·38	—	22	50	22	5·5	—	—	—	—
1·25	—	67	76	13	8	—	—	—	—
1·11	—	160	82	2	—	—	—	—	—
·97	—	240	4	—	—	—	—	—	—
·83	810	78	—	—	—	—	—	—	—
·69	400	30	—	—	—	—	—	—	—
·55	50	—	—	—	—	—	—	—	—

For speeds up to about $1\cdot 5\sqrt{\text{L}}$ there is a definite maximum H.P. at a depth equal to $\text{V}^2/11$ feet (V is in knots). At very high speeds shoal water is usually favourable to the resistance.

Coal Endurance or Radius of Action.

Distance steamed or radius of action in nautical miles

$$= \frac{20\frac{1}{2} \times \text{speed in knots} \times \text{bunker capacity in tons}}{\text{tons of coal used per 24 hours.}}$$

This formula contains a margin for coal untrimmed, and for the effect of variation of draught.

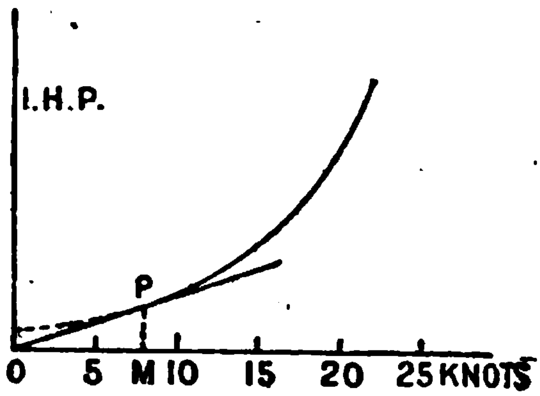
Tons of coal used per 24 hours $=$ horse-power at light draught $\times$ lb. of coal per H.P. per hour (p. 390) $\times \dfrac{24}{2240}$

ECONOMICAL SPEED.

The economical speed of a ship is that in which the radius of action is a maximum.

FIG. 148.

METHOD OF FINDING ECONOMICAL SPEED.



To find, from the origin O of the speed–horse-power curve (fig. 148) draw a tangent touching the curve at P. Then the corresponding speed OM is the economical speed. In large warships the economical speed is usually about 10 or 12 knots.

HORSE-POWER OF WARSHIPS AT LOW SPEEDS.

For large warships, I.H.P. or S.H.P. at 10 knots $= 200 + 3W^{\frac{2}{3}}$ approximately. For small alterations of speed, vary the coefficient of $W^{\frac{2}{3}}$ proportionately to the cube of the speed.

PROPELLERS.

DESIGN OF SCREW PROPELLERS.

(Mr. R. E. Froude, Trans. I.N.A., 1908.)

Let D = diameter of screw in feet.

P = pitch of screw in feet (see note below).

p = P/D = pitch ratio.

H = thrust horse-power (see note below) per screw.

R = revolutions of screw, in hundreds per minute.

V = speed of ship in knots.

V_1 = speed of screw through the water in knots.

$= \dfrac{V}{1+w}$ where w is the wake-factor (see p. 163).

S = real slip ratio $= \dfrac{RP - 1 \cdot 01\, V_1}{RP}$

B = a coefficient depending on the blade area (see table below).

A = area of blade in square feet, including boss.

= actual area excluding boss × 1·25 approximately.

Then $$\frac{H}{D^2 V_1^3} \cdot \frac{p}{B(p+21)} = \cdot 0032162\, \frac{S(1 - \cdot 08\, S)}{(1-S)^2}$$

Notes.—1. The pitch P is determined from the advance of the screw when contributing no thrust. It may be taken to be, on the average, about 1·02 times the pitch of the driving surface.

2. The thrust horse-power is TV_1 (p. 164). It is equal to the effective horse-power divided by the hull efficiency ; the augmentation necessary to include the effect of appendages is not usually included for the purpose of propeller design.

3. The speed $V_1 = V/(1 + w)$; it can be estimated roughly from the wake particulars given on p. 163.

4. The right-hand side of the equation $\cdot 0032162 \dfrac{S(1 - \cdot 08 S)}{(1 - S)^2}$ $(= y)$ is given in the following table :—

S	y	S	y	S	y	S	y
·02	·000067	·14	·000602	·26	·001495	·38	·003086
·04	·000139	·16	·000720	·28	·001698	·40	·003457
·06	·000217	·18	·000849	·30	·001922	·42	·003880
·08	·000302	·20	·000989	·32	·002169	·44	·004354
·10	·000394	·22	·001142	·34	·002442	·46	·004887
·12	·000494	·24	·001311	·36	·002745	·48	·005490

5. The coefficient B depends on the type of blade and on the disc area ratio ; the latter is equal to the fraction $A/\frac{\pi}{4} D^2$.

Disc Area Ratio.	·30	·35	·40	·45	·50	·55	·60	·65	·70	·75	·80
3 blades, elliptical.	·0978	·1020	·1050	·1070	·1085	·1100	·1112	·1124	·1135	·1147	·1157
3 blades, wide tip.	·1045	·1097	·1126	·1148	·1166	·1182	·1195	·1207	·1218	·1230	·1242
4 blades, elliptical.	·1040	·1106	·1159	·1197	·1227	·1249	·1268	·1282	·1294	·1306	·1318

6. Curves of propeller efficiency are shown in fig. 149. They are correct for a 3-blade elliptical propeller, with a disc area ratio of ·45. For a 3-bladed wide tip, the efficiency should be reduced by ·02 ; for a 4-bladed elliptical by ·0125. In addition, a correction for any disc area ratio other than ·45 should be made ; this is very small for all ratios less than ·55 ; for higher ratios, *reduce* the efficiency by the following amounts :—

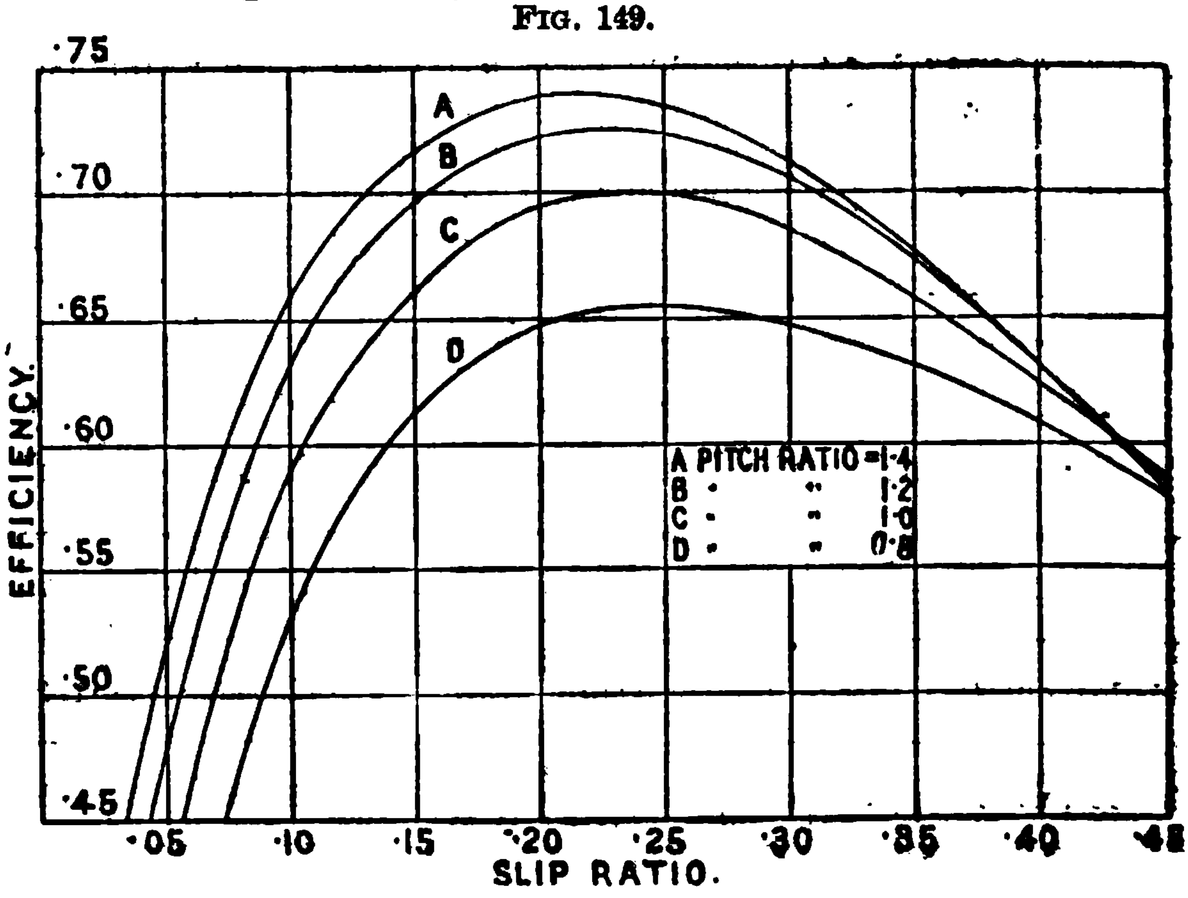
Disc area ratio . . .	—	·55	·65	·70
Deduction for pitch ratio .	·8	·02	·04	·08
,, ,, .	1·0	·01	·03	·05
,, ,, . .	1·2	·005	·015	·025
,, ,, . .	1·4	—	·005	·01

Limitations of Size of Screw.

Frequently a large variety of screw dimensions can be adopted with very little variation in efficiency. In selecting the actual dimensions, the following considerations are of use:—

1. *Fouling diameter.*—There should be not less than 12 inches clearance in large vessels between screw tip and hull. In small ships this allowance may be slightly less. This determines the greatest diameter permissible. By sloping back the blades a propeller of larger diameter can be fitted. With 4 screws the projections of the discs on an athwartship plane should, when practicable, clear one another.

FIG. 149.



CURVE OF SCREW PROPELLER EFFICIENCY.

2. *Cavitation.*—This depends on several factors, including shape of blade, velocity of rubbing, and depth of immersion. As a rough guide, the ratio $\frac{\text{Thrust in tons}}{\text{Blade area in sq. ft.}}$ should not exceed ·75 in ordinary vessels, or ·9 in high-speed vessels, such as destroyers. The blade area here *excludes* the boss, or is equal to ·8 A.

The thrust T is found as described above. Neglecting the appendages $T = H/6{\cdot}8\,V_1$. Hence, area (·8 A) should be at least $H/5{\cdot}1\,V_1$ in ordinary, and $H/7{\cdot}5\,V_1$ in very fast vessels. These are outside limits, and it is preferable to adopt larger areas, if practicable.

Dimensions of Screw.

1. Estimate the E.H.P., or that portion of it given out by the particular screw considered, and (taking data from similar

ships) the hull efficiency and wake percentage. Thence deduce H and V_1.

2. Select various values of disc area ratio (say, ·5, ·6, ·7, and ·8). Note the corresponding values of B.

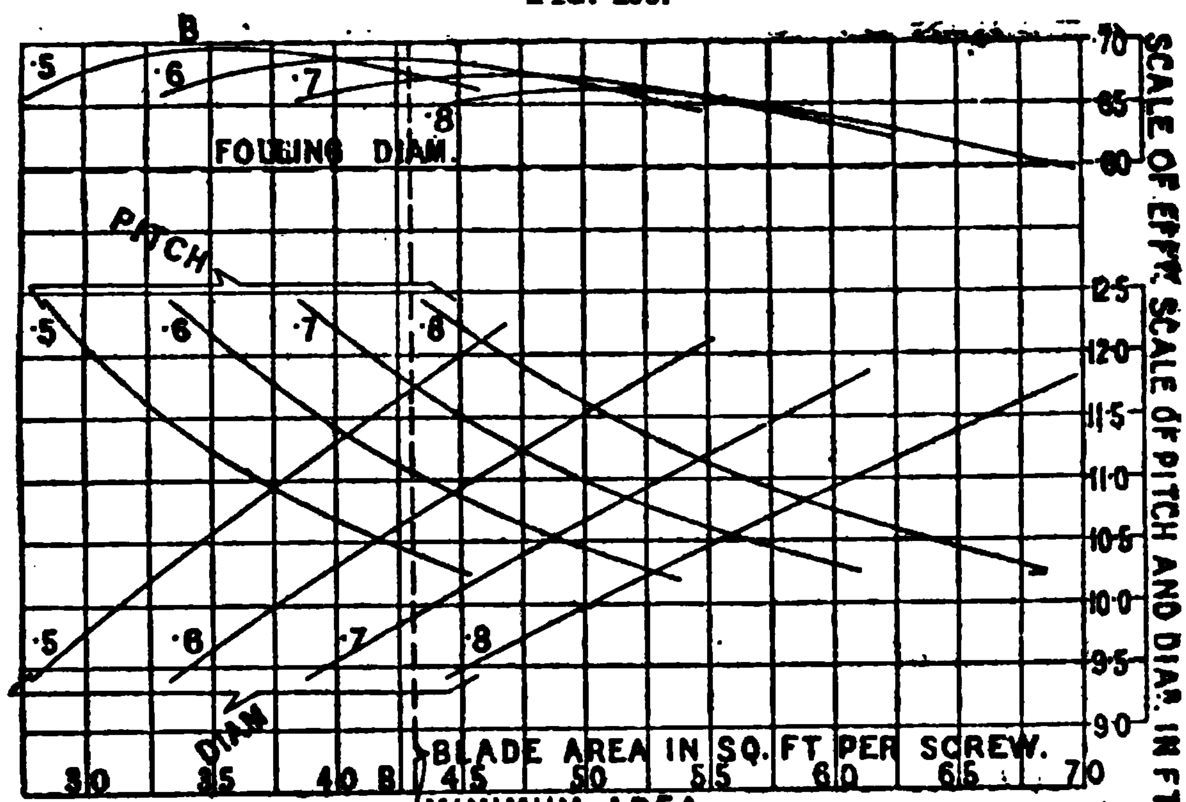
3. For several slip ratios* (S), read off y from the table, and calculate the pitch P from the equation.

$$P = 1\cdot01\, V_1/R\,(1-S).$$

Thence determine the pitch ratio p, using the modified form of the equation above, viz. :—

$$\frac{H}{P^2V_1^3}\cdot\frac{p^3}{B\,(p+21)} = y, \text{ or } p^3/(p+21) = P^2V_1^3\,By/H.$$

FIG. 150.



CURVES OF SCREW PROPELLER DIMENSIONS.

Note.—$p+21$ varies slowly with p, and it can be taken as 22 or thereabouts without great error.

4. Determine from p the diameter D; and from the efficiency curve the screw efficiency.

5. Plot on a base of blade area (·8 A) for various constant disc area ratios (*a*) the pitch, (*b*) the diameter, and (*c*) the efficiency; getting a series of curves as shown on fig. 150.

6. Draw on the diagram straight lines representing the fouling diameter and the minimum area to avoid cavitation.

* The dimensions are usually rather sensitive to changes of slip. The slips should therefore be chosen within narrow limits so as to give practicable pitch ratios.

7. Subject to these limitations any dimensions complying with the curves can be given to the screws. If practical considerations permit, the dimensions selected should be those corresponding to maximum efficiency.

Example.—Determine spot on screw dimension curves corresponding to disc area ratio ·6 and slip ratio ·28 for a vessel of 20,000 E.H.P., four screws, each developing the same power, three-bladed, elliptical, speed 25 knots, hull efficiency 1·02, wake 14 per cent, revolutions per minute 275.

$$\mathrm{V}_1 = \mathrm{V}/(1 + w) = 25/1\cdot14 = 21\cdot9. \quad \mathrm{R} = 2\cdot75.$$

$$\mathrm{H} = \frac{20000}{4 \times 1\cdot02} = 4900. \quad \text{From tables } \mathrm{B} = \cdot1112,\ y = \cdot001698.$$

Then $\mathrm{P} = 1\cdot01\mathrm{V}_1/\mathrm{R}(1 - \mathrm{S}) = 1\cdot01 \times 21\cdot9/2\cdot75 \times \cdot72 = 11\cdot13'$.

$$\frac{p^3}{p + 21} = \frac{\mathrm{P}^2\mathrm{V}_1{}^3\mathrm{B}y}{\mathrm{H}} = \frac{(11\cdot13)^2 \times (21\cdot9)^3 \times \cdot1112 \times \cdot001698}{4900} = \cdot9502.$$

Putting $p + 21 = 22$, $p = 1\cdot033$. $\mathrm{D} = 11\cdot13/1\cdot033 = 10\cdot67'$. Blade area $= \cdot8\,\mathrm{A} = \cdot8 \times \cdot6 \times \cdot785 \times (10\cdot67)^2 = 43\cdot8$. Actual pitch $= \mathrm{P}/1\cdot02 = 10\cdot9'$. Efficiency $= \cdot695$ from curves $- \cdot02$ (correction for disc area ratio) $= \cdot675$. Minimum blade area $= \mathrm{H}/5\cdot1\,\mathrm{V}_1 = 43\cdot9$ sq. ft.

Note.—In the paper by Mr. Froude, from which these particulars are taken, data are given from which curves may be constructed which enable the dimensions to be obtained with reduced arithmetical labour.

Thickness of Blade.

t = thickness of blade at root in inches.
b = breadth of blade at root in inches.
d = diameter of hub in feet.
n = number of blades.

Other symbols as above (see page 190).

$$t^2 = \frac{3\mathrm{H}\,(\mathrm{D} - d)}{nb\,\mathrm{RP}} \text{ for manganese bronze propellers.}$$

Remember that H is only about one-half the I.H.P. per screw.

In vessels running continuously at full speed in all weather, t should be 10 or 20 per cent greater. In cast-iron propellers increase t by about 50 per cent.

Thus, in example above if $b = 40''$, $d = 2'\cdot2$,

$$t^2 = \frac{3 \times 4900 \times 8\cdot47}{3 \times 40 \times 2\cdot75 \times 10\cdot9} \text{ or } t = 5\cdot88''.$$

The thickness would taper gradually from t at the root to a very small minimum value at the tip.

Propulsive Data for Tugs.

Cast-iron Tug Propellers.						
Speed in knots.	I.H.P.	Revs. per min.	Blade area in sq. ft.	No. of Blades.	Pitch.	Diameter.
11·0	455	140	26	3	10′ to 11′	7′ 8″
10·2	416	112	27	4	11′ to 12′	8′ 6″
9·0	240	143	17·4	4	8′	6′ 6″
9·0	190	123	20·8	3	8′	7′ 0″
11·75	827*	102	28	4	14′	8′ 0″
10·2	337	142	17·5	3	8′ 6″	7′ 0″
8·0	106	206	6·25	3	6′ 3″	4′ 3″
10·2	365	118	28	3	9′ 9″	7′ 9″
10·2	360	120	25	3	9′ 6″	8′ 0″
13·0	1400*	118	32	3	12′ 6″	9′ 6″

Average pull on tow rope at low speed = 1 ton per 100 I.H.P.

Towing trials on Thames with swim barges and screw tug of 130 tons displacement.

Number of barges	4	2	1
Displacement of barges in tons	820	440	250
Tow rope pull in tons . . .	3·2	3·3	3·1
Revolutions per minute . . .	99	103	108
Speed in knots	3·3	4·6	6·3
I.H.P.	340	345	350

Note.—The barges were towed close up to the stern, and two abreast except in third trial.

Towing trial on Rhine with four barges.

Total displacement of barges 3,500 tons; towed from 250′ to 950′ behind tug and well staggered so as to be clear of wake. Speed about 6·8 knots relative to stream. I.H.P. 970. Tow rope pull about 8½ tons.

Conclusions derived from towing trials of 'Fulton' and 'Froude'.

(Professor Peabody, Amer. I.N.A. and Mar. Eng.)

The disc area ratio should not be too great, e.g. about ·5.

A small pitch ratio (·8) is best for pulling, and a large pitch ratio (1·5) is favourable when running free. Actually a moderately high pitch ratio is generally used.

Tugs can be powered from the Admiralty coefficient. That for a small model was about 22 when $V/\sqrt{L}$ was ·65.

As great a length of tow-line as practicable should be used. If L represents the length of the tug, increasing the length of line from 2L to 6½L saved 10 per cent of the power;

* Twin screws. Total power given.

but the power when towing abreast was 10 or 12 per cent more than when towing with a length 3L.

PADDLES.

Area of Floats (D. W. Taylor).

A = Combined area of two floats (one on each side) in square feet.

D = mean diameter to centres of floats in feet.

I = indicated horse-power.

R = revolutions in hundreds per minute.

V = speed of ship in knots.

S = slip ratio = $(V_p - V)/V_p$ (where V_p is the peripheral speed in knots of centres of floats) = $(\pi RD - V)/\pi RD$.

$$A = (212\cdot5 - 375\,S)\frac{I}{V^3}$$

S should not greatly exceed ·15 for feathering floats and ·20 for fixed floats; a large slip leads to a low efficiency of propulsion.

Number, size, and position of paddles.

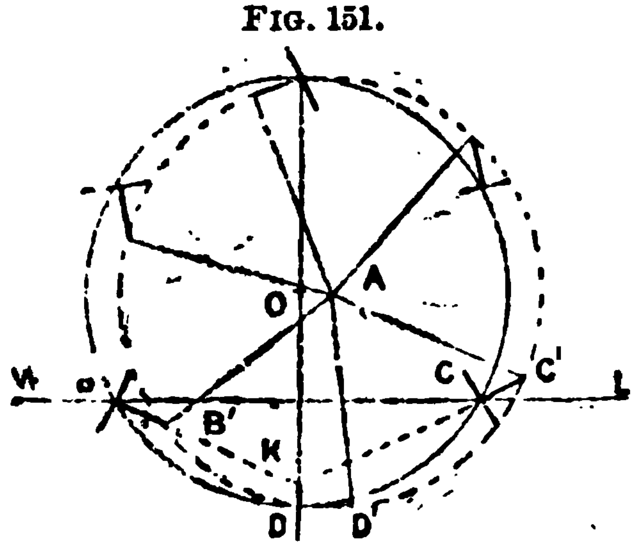
When fixed to the wheel, the floats are spaced about 3 feet apart, or in fast ships slightly less. The spacing of feathering paddles should be 4 to 6 feet. Excessive spacing is liable to cause vibration.

The width of float is about half the beam of the vessel for smooth water, or one-third in seagoing steamers. The depth is determined from the area. Thickness of wood float $= \frac{1}{12}$ width; of steel float in inches $= \cdot15 + (\cdot16 \times$ width in feet).

Paddles should be placed longitudinally so that they run on or near the crest of the wave, which can be determined approximately from experience in similar ships. They must also be near amidships, so as not to be effected by changes of trim, except in stern-wheelers.

The upper edge of the lowest float should be immersed at mean draught about 18 to 20 inches in large sea-going vessels, and about 12 to 15 inches in smaller vessels; about 3 to 6 inches is sufficient in river steamers.

FIG. 151.



Construction for mechanism actuating feathering paddles.

Let WL (fig. 151) be the water-line and O the centre of paddle. It is desirable that the paddles should enter and leave the water without shock; and that in the lowest position they should be vertical. Let B, C, D be centres of paddles in these positions, D being vertically below O. Make KD = OD × slip ratio. Join KB, KC; and make the paddles at B and C perpendicular to these lines. Draw on the positions of the stem-lever ends B′, D′, C′. Find A the centre of a circle passing through B′, C′, D′. Then A is the centre of the eccentric, and all the radius rods must be of length AB′.

SPEED TRIALS.

MEASURED MILE.

To determine the true mean speed of a vessel when the runs are taken on the measured mile, alternately with and against the tide, with approximately equal intervals of time between each run.

RULE.—Multiply the apparent speed in each run by the factor A given in the table below; divide the sum of the products by the number B; the quotient is the required speed.

Note.—This process gives the same result as that obtained by the ordinary 'mean of means' method.

Number of runs.	*Factors A which multiply the speeds in order.*						*Number B.*
3			1	2	1		4
4		1	3	3	1		8
6	1	5	10	10	5	1	32

Example.—The speeds deduced from the times over the mile are 15·4, 10·1, 14·3, 11·0, 13·2, 11·8 knots. Determine the mean speed.

$$\text{Mean speed} = \frac{(15\cdot4+11\cdot8)+5(10\cdot1+13\cdot2)+10(14\cdot3+11\cdot0)}{32}$$

$$= \frac{396\cdot7}{32} = 12\cdot397 \text{ knots approximately.}$$

Note.—The revolutions and I.H.P. or S.H.P. observed during the several runs should be meaned by the same method as the speed.

SPEED OF THE CURRENT.

To find the speeds of the current in the line of the ship's course during her speed trials.

RULE.—Find the differences between the real speed of the ship, as above determined, and her observed speeds on the mile during the several runs.

Example.

Runs	Observed Speed	Real Speed	Differences	
1st	15·4	12·397	3·003	Knots with the ship
2nd	10·1	12·397	2·297	„ against „
3rd	14·3	12·397	1·903	„ with „
4th	11·0	12·397	1·397	„ against „
5th	13·2	12·397	·803	„ with „
6th	11·8	12·367	·597	„ against „

SEA TRIALS.

To determine the true mean speed of a vessel when the distance run is great.

RULE 1ST.—Calculate the apparent speed of each run as usual, by dividing the distance by the time, and group them in sets of three; for example, 1, 2, 3; 2, 3, 4; 3, 4, 5; &c.

2ND.—Each set of three is to be treated as follows:—Find the two intervals of time between the middle instants of the first and second, and of the second and third runs of the set; reduce those intervals to the corresponding angular intervals by the following proportion:—

As $12^h\ 24^m$ (the duration of a tide) : is to a given interval of time :: so is 360° : to the corresponding angular interval.

3RD.—Multiply the *first* apparent speed by the co-secant of the *first* angular interval, the *second* apparent speed by the sum of the co-tangents of the *two* angular intervals, the *third* apparent speed by the co-secant of the *second* angular interval.

4TH.—Add together the products and divide their sum by the sum of the before-mentioned multipliers; the quotient will be a speed from which tidal effects have been eliminated.

5TH.—Add together the velocities deduced from the sets of three runs, and divide by their number for a final mean.

Note.—When an interval elapses of more than a quarter of a tide, or $3^h\ 6^m$, between the middle instants of the two runs of a set, certain multipliers and products must be *subtracted.*

The following example will determine whether these certain multipliers are to be taken as positive or negative.

Example.

Time.	Angles.	Co-secants.	Co tangents.
Between $0^h\ 0^m$ and $3^h\ 6^m$	Between 0° and 90°	Positive	Positive.
Between $3^h\ 6^m$ and $6^h\ 12^m$	Between 90° and 180°	Positive	Negative.
Between $6^h\ 12^m$ and $9^h\ 18^m$	Between 180° and 270°	Negative	Positive.
Between $9^h\ 18^m$ and $12^h\ 24^m$	Between 270° and 360°	Negative	Negative.

TABLE OF COMPARISON OF ADMIRALTY KNOTS AND STATUTE MILES.

Knots	Miles	Knots	Miles	Knots	Miles	Knots	Miles	Knots	Miles
1·00	1·1515	6·00	6·9091	11·00	12·6667	16·00	18·4242	21·00	24·181
1·25	1·4394	6·25	7·1970	11·25	12·9545	16·25	18·7121	21·25	24·469
1·50	1·7273	6·50	7·4848	11·50	13·2424	16·50	19·0000	21·50	24·757
1·75	2·0152	6·75	7·7727	11·75	13·5303	16·75	19·2879	21·75	25·045
2·00	2·3030	7·00	8·0606	12·00	13·8182	17·00	19·5758	22·00	25·333
2·25	2·5909	7·25	8·3485	12·25	14·1061	17·25	19·8636	22·25	25·621
2·50	2·8788	7·50	8·6364	12·50	14·3939	17·50	20·1515	22·50	25·909
2·75	3·1667	7·75	8·9242	12·75	14·6818	17·75	20·4394	22·75	26·197
3·00	3·4545	8·00	9·2121	13·00	14·9697	18·00	20·7273	23·00	26·484
3·25	3·7424	8·25	9·5000	13·25	15·2576	18·25	21·0152	23·25	26·772
3·50	4·0303	8·50	9·7879	13·50	15·5455	18·50	21·3030	23·50	27·060
3·75	4·3182	8·75	10·0758	13·75	15·8333	18·75	21·5909	23·75	27·348
4·00	4·6061	9·00	10·3636	14·00	16·1212	19·00	21·8788	24·00	27·636
4·25	4·8939	9·25	10·6515	14·25	16·4091	19·25	22·1667	24·25	27·924
4·50	5·1818	9·50	10·9394	14·50	16·6970	19·50	22·4545	24·50	28·212
4·75	5·4697	9·75	11·2273	14·75	16·9848	19·75	22·7424	24·75	28·500
5·00	5·7576	10·00	11·5152	15·00	17·2727	20·00	23·0303	25·00	28·787
5·25	6·0455	10·25	11·8030	15·25	17·5606	20·25	23·3182	25·25	29·075
5·50	6·3333	10·50	12·0909	15·50	17·8485	20·50	23·6061	25·50	29·363
5·75	6·6212	10·75	12·3788	15·75	18·1364	20·75	23·8939	25·75	29·651

Miles	Knots	Miles	Knots	Miles	Knots	Miles	Knots	Miles	Knots
1·00	·8684	6·00	5·2105	11·00	9·5526	16·00	13·8947	21·00	18·236
1·25	1·0855	6·25	5·4276	11·25	9·7697	16·25	14·1118	21·25	18·453
1·50	1·3026	6·50	5·6447	11·50	9·9868	16·50	14·3289	21·50	18·671
1·75	1·5197	6·75	5·8618	11·75	10·2039	16·75	14·5461	21·75	18·888
2·00	1·7368	7·00	6·0789	12·00	10·4211	17·00	14·7632	22·00	19·105
2·25	1·9539	7·25	6·2961	12·25	10·6382	17·25	14·9803	22·25	19·322
2·50	2·1711	7·50	6·5132	12·50	10·8553	17·50	15·1974	22·50	19·539
2·75	2·3882	7·75	6·7303	12·75	11·0724	17·75	15·4145	22·75	19·756
3·00	2·6053	8·00	6·9474	13·00	11·2895	18·00	15·6316	23·00	19·973
3·25	2·8224	8·25	7·1645	13·25	11·5066	18·25	15·8487	23·25	20·190
3·50	3·0395	8·50	7·3816	13·50	11·7237	18·50	16·0658	23·50	20·407
3·75	3·2566	8·75	7·5987	13·75	11·9408	18·75	16·2829	23·75	20·625
4·00	3·4737	9·00	7·8158	14·00	12·1579	19·00	16·5000	24·00	20·842
4·25	3·6908	9·25	8·0329	14·25	12·3750	19·25	16·7171	24·25	21·059
4·50	3·9079	9·50	8·2500	14·50	12·5921	19·50	16·9342	24·50	21·276
4·75	4·1250	9·75	8·4671	14·75	12·8092	19·75	17·1513	24·75	21·493
5·00	4·3421	10·00	8·6842	15·00	13·0263	20·00	17·3684	25·00	21·710
5·25	4·5592	10·25	8·9013	15·25	13·2434	20·25	17·5855	25·25	21·927
5·50	4·7763	10·50	9·1184	15·50	13·4605	20·50	17·8026	25·50	22·144
5·75	4·9934	10·75	9·3355	15·75	13·6776	20·75	18·0197	25·75	22·361

N.B. The Admiralty knot = 6,080 ft.; 1 statute mile = 5,280 ft.

Table of Kilometres to Admiralty Knots and Admiralty Knots to Kilometres.

Kilos.	Knots	Kilos.	Knots	Kilos.	Knots	Kilos.	Knots	Kilos.	Knots
1·0	·540	8·0	4·317	15·0	8·094	22·0	11·872	29·0	15·649
1·25	·675	8·25	4·452	15·25	8·229	22·25	12·006	29·25	15·784
1·5	·809	8·5	4·587	15·5	8·364	22·5	12·141	29·5	15·919
1·75	·944	8·75	4·722	15·75	8·499	22·75	12·276	29·75	16·054
2·0	1·079	9·0	4·857	16·0	8·634	23·0	12·411	30·0	16·188
2·25	1·214	9·25	4·991	16·25	8·769	23·25	12·546	30·25	16·323
2·5	1·349	9·5	5·126	16·5	8·904	23·5	12·681	30·5	16·458
2·75	1·484	9·75	5·261	16·75	9·039	23·75	12·816	30·75	16·593
3·0	1·619	10·0	5·396	17·0	9·173	24·0	12·951	31·0	16·728
3·25	1·754	10·25	5·531	17·25	9·308	24·25	13·086	31·25	16·863
3·5	1·889	10·5	5·666	17·5	9·443	24·5	13·221	31·5	16·998
3·75	2·024	10·75	5·801	17·75	9·578	24·75	13·356	31·75	17·133
4·0	2·158	11·0	5·936	18·0	9·713	25·0	13·490	32·0	17·268
4·25	2·293	11·25	6·071	18·25	9·848	25·25	13·625	32·25	17·403
4·5	2·428	11·5	6·206	18·5	9·983	25·5	13·760	32·5	17·538
4·75	2·563	11·75	6·340	18·75	10·118	25·75	13·895	32·75	17·672
5·0	2·698	12·0	6·475	19·0	10·253	26·0	14·030	33·0	17·807
5·25	2·833	12·25	6·610	19·25	10·388	26·25	14·165	33·25	17·942
5·5	2·968	12·5	6·745	19·5	10·523	26·5	14·300	33·5	18·077
5·75	3·103	12·75	6·880	19·75	10·657	26·75	14·435	33·75	18·212
6·0	3·238	13·0	7·015	20·0	10·792	27·0	14·570	34·0	18·347
6·25	3·373	13·25	7·150	20·25	10·927	27·25	14·705	34·25	18·482
6·5	3·508	13·5	7·285	20·5	11·062	27·5	14·839	34·5	18·617
6·75	3·642	13·75	7·420	20·75	11·197	27·75	14·974	34·75	18·752
7·0	3·777	14·0	7·555	21·0	11·332	28·0	15·109	35·00	18·887
7·25	3·912	14·25	7·690	21·25	11·467	28·25	15·244	35·25	19·021
7·5	4·047	14·5	7·824	21·5	11·602	28·5	15·379	35·5	19·156
7·75	4·182	14·75	7·959	21·75	11·737	28·75	15·514	35·75	19·291

Knots	Kilos.	Knots	Kilos.	Knots	Kilos.	Knots	Kilos.	Knots	Kilos.
1·0	1·853	4·75	8·803	8·5	15·752	12·25	22·701	16·0	29·651
1·25	2·316	5·0	9·266	8·75	16·215	12·5	23·165	16·25	30·114
1·5	2·780	5·25	9·729	9·0	16·679	12·75	23·628	16·5	30·577
1·75	3·243	5·5	10·192	9·25	17·142	13·0	24·091	16·75	31·041
2·0	3·706	5·75	10·656	9·5	17·605	13·25	24·554	17·0	31·504
2·25	4·170	6·0	11·119	9·75	18·068	13·5	25·018	17·25	31·967
2·5	4·633	6·25	11·582	10·0	18·532	13·75	25·481	17·5	32·430
2·75	5·096	6·5	12·046	10·25	18·995	14·0	25·944	17·75	32·894
3·0	5·560	6·75	12·509	10·5	19·458	14·25	26·408	18·0	33·357
3·25	6·023	7·0	12·972	10·75	19·922	14·5	26·871	18·25	33·820
3·5	6·486	7·25	13·435	11·0	20·385	14·75	27·334	18·5	34·284
3·75	6·949	7·5	13·899	11·25	20·848	15·0	27·798	18·75	34·747
4·0	7·413	7·75	14·362	11·5	21·311	15·25	28·261	19·0	35·210
4·25	7·876	8·0	14·825	11·75	21·775	15·5	28·724	19·25	35·673
4·5	8·339	8·25	15·289	12·0	22·238	15·75	29·187	19·5	36·137

Effect on Speed and Power of Increase of Resistan

If H.P. = KV^n (see p. 169), and K is increased *moderat* through foul bottom, or increased draught, or any other sou of additional resistance, the speed V is decreased and t power H increased by the percentage in the following tab which should be multiplied by the percentage increase in The rate of revolution of the propeller is assumed constant.

Real Slip Ratio	$n = 3$ $-\%V$	$n = 3$ $+\%H$	$n = 4$ $-\%V$	$n = 4$ $+\%H$	$n = 5$ $-\%V$	$n = 5$ $+\%H$
·20	·17	·50	·14	·48	·12	·38
·25	·20	·40	·17	·33	·14	·29
·30	·23	·31	·19	·25	·16	·21
·35	·26	·22	·21	·18	·17	·15
·40	·29	·14	·22	·11	·18	·09

Principal Measured Distances off the British Isles

Place.	Measured distance in feet.	True course.	Approxima depth of water at lo water sprin tides in fathoms.
East Coast of England.			
Tyne River	6080	341°	11 to 12
Colne River	3035	333°	7 to 13
,, ...	3048	346°	
Thames River Lower Hope .	6080	25°	4¼ to 4½
Thames River Maplin . .	6080	67°	6 to 8
South Coast of England.			
Stokes Bay	6080	295°	10 to 13
Southampton Water . .	5888	126°	2 to 2¾
*Portland (Chesil Beach) . .	8678	314°	17
*Polperro	6990	266°	17 to 20
Plymouth (Outer) . . .	6080	273°	11 to 15
,, (Inner) . . .	4562	275°	5 to 6½
Falmouth	6989	347°	3 to 5
West Coast of England.			
Barrow	6080	329°	3½ to 5
West Coast of Scotland.			
Skelmorlie	6080	0°	36 to 42
Gare Loch	6080	336°	15 to 22
East Coast of Scotland.			
St. Abbs Head	6084	291°	24 to 28
Tay River	6080	266°	4½ to 6½
Ireland.			
Belfast Lough	6080	265°	5½ to 6

* In order to use the following speed tables for the Portland course, first dedu 30 per cent. (29·94 accurately) from the times; for the Polperro course add 15 per ce (14·97 accurately) to the speeds deduced from the tables.

Speed Table for Measured Course of 6,080 Feet.

Secs.	1 Minute.											
0	30	40·000	35	37·895	40	36·000	45	34·286	50	32·727	55	31·304
·1		39·956		·855		35·964		·253		·698		·277
·2		·911		·815		·928		·221		·668		·250
·3		·867		·775		·892		·188		·638		·223
·4		·823		·736		·857		·156		·609		·196
·5		·779		·696		·821		·123		·579		·169
·6		·735		·657		·785		·091		·550		·142
·7		·691		·618		·750		·059		·520		·115
·8		·648		·578		·714		·026		·491		·088
·9		·604		·539		·679		33·994		·462		·061
0	31	39·560	36	37·500	41	35·644	46	33·962	51	32·432	56	31·034
·1		·517		·461		·608		·930		·403		·008
·2		·474		·422		·573		·898		·374		30·981
·3		·430		·383		·533		·866		·345		·954
·4		·387		·344		·503		·835		·316		·928
·5		·344		·306		·468		·803		·287		·901
·6		·301		·267		·433		·771		·258		·875
·7		·258		·229		·398		·739		·229		·848
·8		·216		·190		·363		·708		·200		·822
·9		·173		·152		·329		·676		·172		·796
0	32	39·130	37	37·113	42	35·294	47	33·645	52	32·143	57	30·769
·1		·088		·075		·260		·613		·114		·743
·2		·046		·037		·225		·582		·086		·717
·3		·003		36·999		·191		·551		·057		·691
·4		38·961		·961		·156		·520		·028		·664
·5		·919		·923		·122		·488		·000		·638
·6		·877		·885		·088		·457		31·972		·612
·7		·835		·847		·053		·426		·943		·586
·8		·793		·810		·019		·395		·915		·560
·9		·751		·772		34·985		·364		·887		·534
0	33	38·710	38	36·735	43	34·951	48	33·333	53	31·858	58	30·508
·1		·668		·697		·918		·302		·830		·483
·2		·627		·660		·884		·272		·802		·457
·3		·585		·623		·850		·241		·774		·431
·4		·544		·585		·816		·210		·746		·405
·5		·503		·548		·783		·180		·718		·380
·6		·462		·511		·749		·149		·690		·354
·7		·421		·474		·716		·119		·662		·329
·8		·380		·437		·682		·088		·634		·303
·9		·339		·400		·649		·058		·607		·278
0	34	38·298	39	36·364	44	34·615	49	33·028	54	31·579	59	30·252
·1		·257		·327		·582		32·997		·551		·227
·2		·217		·290		·549		·967		·524		·201
·3		·176		·254		·516		·937		·496		·176
·4		·136		·217		·483		·907		·469		·151
·5		·095		·181		·450		·877		·441		·126
·6		·055		·145		·417		·847		·414		·100
·7		·015		·108		·384		·817		·386		·075
·8		37·975		·072		·351		·787		·359		·050
·9		·935		·036		·318		·757		·332		·025
0	35	37·895	40	36·000	45	34·286	50	32·727	55	31·304	60	30·000

Speed Table for Measured Course of 6,080 Feet.

Secs.	2 Minutes.											
0	0	30·000	10	27·692	20	25·714	30	24·000	40	22·500	50	21·176
·2		29·950		·650		·678		23·968		·472		·152
·4		·900		·607		·641		·936		·444		·127
·6		·850		·565		·605		·904		·416		·102
·8		·801		·523		·568		·873		·388		·077
0	1	29·752	11	27·481	21	25·532	31	23·841	41	22·360	51	21·053
·2		·703		·439		·496		·810		·333		·028
·4		·654		·397		·460		·778		·305		·004
·6		·605		·356		·424		·747		·277		20·979
·8		·556		·314		·388		·715		·250		·955
0	2	29·508	12	27·273	22	25·352	32	23·684	42	22·222	52	20·930
·2		·460		·232		·316		·653		·195		·906
·4		·412		·191		·281		·622		·167		·882
·6		·364		·150		·245		·591		·140		·857
·8		·316		·109		·210		·560		·113		·833
0	3	29·268	13	27·068	23	25·175	33	23·529	43	22·086	53	20·809
·2		·221		·027		·140		·499		·059		·785
·4		·173		26·987		·105		·468		·032		·761
·6		·126		·946		·070		·438		·005		·737
8		·079		·906		·035		·407		21·978		·713
0	4	29·032	14	26·866	24	25·000	34	23·377	44	21·951	54	20·690
·2		28·986		·826		24·965		·346		·924		·666
·4		·939		·786		·930		·316		·898		·642
·6		·892		·746		·896		·286		·871		·619
·8		·846		·706		·862		·256		·845		·595
0	5	28·800	15	26·667	25	24·828	35	23·226	45	21·818	55	20·571
·2		·754		·627		·794		·196		·792		·548
·4		·708		·588		·760		·166		·766		·525
·6		·662		·549		·726		·136		·739		·501
·8		·617		·510		·692		·107		·713		·478
0	6	28·571	16	26·471	26	24·658	36	23·077	46	21·687	56	20·455
·2		·526		·432		·624		·047		·661		·431
·4		·481		·393		·590		·018		·635		·408
·6		·436		·354		·557		22·989		·609		·385
·8		·391		·316		·523		·959		·583		·362
0	7	28·346	17	26·277	27	24·490	37	22·930	47	21·557	57	20·339
·2		·302		·239		·457		·901		·531		·316
·4		·257		·201		·423		·872		·505		·293
·6		·213		·163		·390		·843		·480		·270
·8		·169		·125		·357		·814		·454		·247
0	8	28·125	18	26·087	28	24·324	38	22·785	48	21·429	58	20·225
·2		·081		·049		·291		·756		·403		·202
·4		·037		·012		·259		·727		·378		·179
·6		27·994		25·974		·226		·699		·352		·157
·8		·950		·937		·194		·670		·327		·134
0	9	27·907	19	25·899	29	24·161	39	22·642	49	21·302	59	20·112
·2		·864		·862		·129		·613		·277		·089
·4		·821		·825		·096		·585		·251		·067
·6		·778		·788		·064		·556		·226		·045
·8		·735		·751		·032		·528		·201		·022
0	10	27·692	20	25·714	30	24·000	40	22·500	50	21·176	60	20·000

Speed Table for Measured Course of 6,080 Feet.

Secs.	3 Minutes.												
0	0	20·000	10	18·947	20	18·000	30	17·143	40	16·364		
·2		19·978		·927		17·982		·127		·349		
·4		·956		906		·964		·110		·334		
·6		·934		888		·946		·094		·319		
[illegible]		·912		·868		·928		·078		·304		
0	1	19·890	11	18·848	21	17·910	31	17·062	41	16·290		
·2		·868		·828		·893		·045		·275		
·4		·846		[illegible]		·875		·029		·260		
·6		·824		·789		·857		·013		·245		
·8		·802		·770		·839		16·997		·231		
0	2	19·780	12	18·750	22	17·822	32	16·981	42	16·216		
·2		·759		·731		·804		[illegible]		·202		
·4		·737		·711		·787		·949		·187		
·6		·716		·692		·769		·933		·173		
·8		·694		·672		751		·917		[illegible]		
0	3	19·672	13	18·653	23	17·734	33	16·901	43	16·143		
·2		·651		·634		·717		·886		129		
·4		·629		·614		·699		·870		115		
·6		·608		·595		·682		·854		100		
·8		·587		576		·664		·838		·086		
0	4	19·565	14	18·557	24	17·647	34	16·822	44	16·071		
·2		·544		538		·630		·807		·057		
·4		·523		·519		·613		·791		·043		
·6		502		·499		·596		·775		·028		
·8		·481		·480		·578		·760		·014		
0	5	19·459	15	18·461	25	17·561	35	16·744	45	16·000		
·2		438		·443		544		·729		15·986		
·4		·417		424		·527		·713		·972		
·6		·397		·405		·510		·697		·957		
·8		·376		·386		·493		682		·943		
0	6	19·355	16	18·367	26	17·476	36	16·667	46	15·929		
·2		334		349		459		·651		·915		
·4		·313		·330		·442		·636		·901		
·6		·292		·311		·425		·620		·887		
·8		·271		·293		·408		·605		·873		
0	7	19·251	17	18·274	27	17·391	37	16·590	47	15·859	57	15·1
·2		·230		·256		·375		·575		·845		·1
·4		·210		·237		·358		·559		·831		·1
·6		·190		219		311		514		817		·1
·8		·169		200		324		529		·803		·1
0	8	19·149	18	18·182	28	17·308	38	16·511	48	15·789	58	15·1
·2		·129		163		291		·499		·776		·1
·4		·108		145		·274		·484		·762		·1
·6		·088		·127		·258		·468		·748		·0
·8		·068		·109		·241		·453		·734		·0
0	9	19·048	19	18·090	29	17·225	39	16·438	49	15·721	59	15·0
·2		·027		·072		208		·423		·707		·0
·4		·007		054		·192		408		·693		·0
·6		18·987		·036		·176		393		·679		·0
·8		967		·018		·159		·379		·666		·0
0	10	18·947	20	18·000	30	17·143	40	16·364	50	15·652	60	15·00

Speed Table for Measured Course of 6,080 Feet.

4 Minutes.

0	15·000	10	14·400	20	13·846	30	13·333	40	12·857	50	12·414
	14·988		·388		·836		·323		·848		·405
	·975		·377		·825		·314		·839		·397
	·963		·366		·814		·304		·830		·388
	·950		·354		·804		·294		·821		·380
1	14·938	11	14·343	21	13·793	31	13·284	41	12·811	51	12·371
	·925		·331		·783		·274		·802		·363
	·913		·320		·772		·265		·793		·354
	·901		·308		·761		·255		·784		·346
	·888		·297		·751		·245		·775		·337
2	14·876	12	14·286	22	13·740	32	13·235	42	12·766	52	12·329
	·864		·274		·730		·225		·757		·320
	·851		·263		·720		·216		·748		·312
	·839		·252		·709		·206		·739		·303
	·827		·241		·699		·196		·730		·295
3	14·815	13	14·229	23	13·688	33	13·187	43	12·721	53	12·287
	·803		·218		·678		·177		·712		·278
	·790		·207		·667		·167		·703		·270
	·778		·196		·657		·158		·694		·262
	·766		·184		·647		·148		·685		·253
4	14·754	14	14·173	24	13·636	34	13·139	44	12·676	54	12·245
	·742		·162		·626		·129		·667		·237
	·730		·151		·616		·120		·658		·228
	·718		·140		·605		·110		·649		·220
	·706		·129		·595		·100		·640		·212
5	14·694	15	14·118	25	13·585	35	13·091	45	12·632	55	12·203
	·682		·107		·575		·081		·623		·195
	·670		·096		·564		·072		·614		·187
	·658		·085		·554		·062		·605		·179
	·646		·074		·544		·053		·596		·170
6	14·634	16	14·063	26	13·534	36	13·043	46	12·587	56	12·162
	·622		·052		·524		·034		·579		·154
	·610		·041		·514		·025		·570		·146
	·599		·030		·503		·015		·561		·138
	·587		·019		·493		·006		·552		·129
7	14·575	17	14·008	27	13·483	37	12·996	47	12·544	57	12·121
	·563		13·997		·473		·987		·535		·113
	·551		·986		·463		·978		·526		·105
	·540		·975		·453		·968		·517		·097
	·528		·964		·443		·959		·509		·089
8	14·516	18	13·953	28	13·433	38	12·950	48	12·500	58	12·081
	·504		·943		·423		·940		·491		·072
	·493		·932		·413		·931		·483		·064
	·481		·921		·403		·922		·474		·056
	·469		·910		·393		·912		·465		·048
9	14·458	19	13·900	29	13·383	39	12·903	49	12·457	59	12·040
	·446		·889		·373		·894		·448		·032
	·435		·878		·363		·885		·440		·024
	·423		·867		·353		·876		·431		·016
	·412		·857		·343		·866		·422		·008
10	14·400	20	13·846	30	13·333	40	12·857	50	12·414	60	12·000

Speed Table for Measured Course of 6,080 Feet.

5 Minutes.

Secs.												
0	0	12·000	10	11·613	20	11·250	30	10·909	40	10·588	50	10·286
·2		11·992		·605		·243		·902		·582		·280
·4		·984		·598		·236		·896		·576		·274
·6		·976		·590		·229		·889		·570		·268
·8		·968		·583		·222		·883		·563		·262
0	1	11·960	11	11·576	21	11·215	31	10·876	41	10·557	51	10·256
·2		·952		·568		·208		·870		·551		·251
·4		·944		·561		·201		·863		·545		·245
·6		·936		·553		·194		·857		·539		·239
·8		·928		·546		·187		·850		·532		·233
0	2	11·921	12	11·538	22	11·180	32	10·843	42	10·526	52	10·227
·2		·913		·531		·173		·837		·520		·221
·4		905		·524		·166		·830		·514		·216
·6		·897		·516		·159		·824		·508		·210
·8		·889		·509		·152		·817		·502		·204
0	3	11·881	13	11·502	23	11·146	33	10·811	43	10·496	53	10·198
·2		·873		·494		·139		·804		·490		·193
·4		·866		·487		·132		·798		·483		·187
·6		·858		·480		·125		·791		·477		·181
·8		·850		·472		·118		·785		·471		·175
0	4	11·842	14	11·465	24	11·111	34	10·778	44	10·465	54	10·169
·2		·834		·458		·104		·772		·459		·164
·4		·827		·450		·097		·766		·453		·158
·6		·819		·443		·091		·759		·447		·152
·8		·811		·436		·084		·753		·441		·147
0	5	11·803	15	11·429	25	11·077	35	10·746	45	10·435	55	10·141
·2		·796		·421		·070		·740		·429		·135
·4		·788		·414		·063		·733		·423		·129
·6		·780		·407		·057		·727		·417		·124
·8		·772		·400		·050		·721		·411		·118
0	6	11·765	16	11·392	26	11·043	36	10·714	46	10·405	56	10·112
·2		·757		·385		·036		·708		·399		·107
·4		·749		·378		·029		·702		·393		·101
·6		·742		·371		·023		·695		·387		·095
·8		·734		·364		·016		·689		·381		·090
0	7	11·726	17	11·356	27	11·009	37	10·683	47	10·375	57	10·084
·2		·719		·349		·002		·676		·369		·078
·4		·711		·342		10·996		·670		·363		·073
·6		·704		·335		·989		·664		·357		·067
·8		·696		·328		·982		·657		·351		·061
0	8	11·688	18	11·321	28	10·976	38	10·651	48	10·345	58	10·056
·2		·681		·314		·969		·645		·339		·050
·4		·673		·307		·962		·638		·333		·045
·6		·666		·299		·956		·632		·327		·039
·8		·658		·292		·949		·626		·321		·033
0	9	11·650	19	11·285	29	10·942	39	10·619	49	10·315	59	10·028
·2		·643		·278		·936		·613		·309		·022
·4		·635		·271		·929		·607		·303		·017
·6		·628		·264		·922		·601		·297		·011
·8		·620		·257		·916		·594		·292		·006
0	10	11·613	20	11·250	30	10·909	40	10·588	50	10·286	60	10·000

Speed Table for Measured Course of 6,080 Feet.

6 Minutes.

Secs.											
0	10·000	10	9·730	20	9·474	30	9·231	40	9·000	50	8·780
1	9·972	11	9·704	21	9·449	31	9·207	41	8·978	51	8·759
2	9·945	12	9·677	22	9·424	32	9·184	42	8·955	52	8·738
3	9·917	13	9·651	23	9·399	33	9·160	43	8·933	53	8·717
4	9·890	14	9·626	24	9·375	34	9·137	44	8·911	54	8·696
5	9·863	15	9·600	25	9·351	35	9·114	45	8·889	55	8·675
6	9·836	16	9·574	26	9·326	36	9·091	46	8·867	56	8·654
7	9·809	17	9·549	27	9·302	37	9·068	47	8·845	57	8·633
8	9·783	18	9·524	28	9·278	38	9·045	48	8·824	58	8·612
9	9·756	19	9·499	29	9·254	39	9·023	49	8·802	59	8·592

7 Minutes.

0	8·571	10	8·372	20	8·182	30	8·000	40	7·826	50	7·660
1	8·551	11	8·353	21	8·163	31	7·982	41	7·809	51	7·643
2	8·531	12	8·333	22	8·145	32	7·965	42	7·792	52	7·627
3	8·511	13	8·314	23	8·126	33	7·947	43	7·775	53	7·611
4	8·491	14	8·295	24	8·108	34	7·930	44	7·759	54	7·595
5	8·471	15	8·276	25	8·090	35	7·912	45	7·742	55	7·579
6	8·451	16	8·257	26	8·072	36	7·895	46	7·725	56	7·563
7	8·431	17	8·238	27	8·054	37	7·877	47	7·709	57	7·547
8	8·411	18	8·219	28	8·036	38	7·860	48	7·692	58	7·531
9	8·392	19	8·200	29	8·018	39	7·843	49	7·676	59	7·516

8 Minutes.

0	7·500	10	7·347	20	7·200	30	7·059	40	6·923	50	6·792
1	7·484	11	7·332	21	7·186	31	7·045	41	6·910	51	6·780
2	7·469	12	7·317	22	7·171	32	7·031	42	6·897	52	6·767
3	7·453	13	7·302	23	7·157	33	7·018	43	6·883	53	6·754
4	7·438	14	7·287	24	7·143	34	7·004	44	6·870	54	6·742
5	7·423	15	7·273	25	7·129	35	6·990	45	6·857	55	6·729
6	7·407	16	7·258	26	7·115	36	6·977	46	6·844	56	6·716
7	7·392	17	7·243	27	7·101	37	6·963	47	6·831	57	6·704
8	7·377	18	7·229	28	7·087	38	6·950	48	6·818	58	6·691
9	7·362	19	7·214	29	7·073	39	6·936	49	6·805	59	6·679

9 Minutes.

0	6·667	10	6·545	20	6·429	30	6·316	40	6·207	50	6·102
1	6·654	11	6·534	21	6·417	31	6·305	41	6·196	51	6·091
2	6·642	12	6·522	22	6·406	32	6·294	42	6·186	52	6·081
3	6·630	13	6·510	23	6·394	33	6·283	43	6·175	53	6·071
4	6·618	14	6·498	24	6·383	34	6·272	44	6·164	54	6·061
5	6·606	15	6·486	25	6·372	35	6·261	45	6·154	55	6·050
6	6·593	16	6·475	26	6·360	36	6·250	46	6·143	56	6·040
7	6·581	17	6·463	27	6·349	37	6·239	47	6·133	57	6·030
8	6·569	18	6·452	28	6·338	38	6·228	48	6·122	58	6·020
9	6·557	19	6·440	29	6·327	39	6·218	49	6·112	59	6·010

SAILING.

Centre of Lateral Resistance.

The centre of lateral resistance is the centre of application of resistance of the water; and as this varies in position with the speed of the ship, &c., it is not determinate, but a point is generally taken at the centre of the immersed longitudinal vertical middle plane of the vessel as sufficiently accurate.

Centre of Effort.

The point in the longitudinal vertical middle plane of a vessel which is traversed by the resultant of the pressure of the wind on the sails is termed the centre of effort; its position varies according to the quantity of sail spread, &c., but its position is determined approximately for purposes connected with designing the sails, all plain sail only being taken—that is, the sails that are more commonly used, and which can be carried with safety in a fresh breeze (see table, p. 210). They are as follows:—

In square-rigged vessels: the fore and main courses, fore, main, and mizen topsails, fore, main, and mizen topgallant sails, driver, jib, and sometimes the fore topmast staysail.

In fore and aft rigged vessels: the main sail, fore sail, and sometimes the second or third jib.

In calculating the position of the centre of effort the sails are taken braced right fore and aft.

The centre of gravity of the whole sail area is calculated by the ordinary rules for the C.G. of a geometrical area (p. 59 and after).

Ardency.

Ardency is the tendency a ship has to fly up to the wind, thus showing that the position of her centre of effort * is abaft the centre of lateral resistance.

Slackness.

Slackness is the tendency a ship has to fall off from the wind, thus showing that the position of her centre of effort is before the centre of lateral resistance.

Relative Position of Centre of Effort and Centre of Lateral Resistance.

The calculated centre of effort lies usually between ·01 L and ·03 L before the centre of lateral resistance, L being the length of ship. With a large fine deadwood aft, this distance

* This refers to her real, not her calculated, centre. The latter may be slightly before the centre of lateral resistance.

should be slightly diminished. In many sailing boats the two centres are coincident laterally. If the centre of effort be too far forward, the vessel becomes 'slack' and will not readily go about; if too far aft, the vessel may be too 'ardent'.

Power to Carry Sail.

The vertical distance between the centres of effort and lateral resistance ($= h$ feet) is arranged in accordance with the following formula:—

W = displacement of vessel in tons.
GM = metacentric height in feet.
A = sail area (plain sail only) in square feet.

$$\text{Power to carry sail} = \frac{2240\, W \,.\, GM}{A \,.\, h}$$

The power to carry sail is about 3 to 3·5 in sailing boats, about 3 for yachts, and about 15 in auxiliary ships such as sloops.

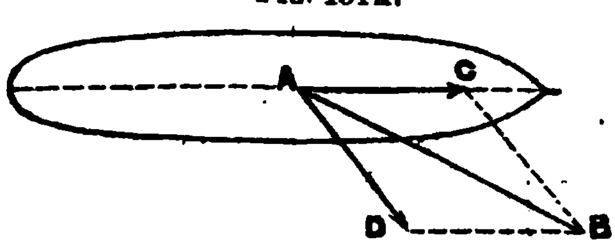
Note.—The power to carry sail is approximately the reciprocal of the angle in radians to which the vessel will heel under a wind pressure of 1 lb. per square foot of sail (corresponding to a breeze of about 16 knots on the beam).

Real and Apparent Motion of the Wind.

By the real motion of the wind is meant its motion relatively to the earth, and by its apparent motion its motion relatively to the ship when she is sailing.

The apparent motion being the resultant of the real motion of the wind and of a motion equal and directly opposite to that of the ship.

Fig. 151A.



In fig. 151A let AB represent in magnitude and direction the real motion of the wind, and AC the direction and velocity of the motion of the ship; through B draw BD parallel and equal to AC; join DA: then DA will represent in magnitude and direction the apparent motion of the wind.

Sail Area.

The sail area in regard to size of ship may be determined approximately from the *driving power*, which is about the same in similar vessels.

A = sail area in square feet.
W = displacement in tons.

Then $A/W^{\frac{2}{3}}$ = driving power (see p. 184 for table of $W^{\frac{2}{3}}$).
This is approximately 180 in sailing boats, 200 in yachts, and 80 in sloops where sails are carried as auxiliary to steam.

SPECIFICATION OF THE BEAUFORT SCALE WITH PROBABL

(From Report of the Advisory Committee fo

Beaufort No. B.	Admiral Beaufort's general description of wind.	Admiral Beaufort's specification, 1805.		Description of wind.	Mode of estimating aboard sailing vessels.
0	Calm . . .	Calm.		—	—
1	Light air .	Just sufficient to give steerage way.		Light breeze	Sufficient wind fo working ship.
2	Slight breeze	That in which a well-conditioned man-of-war with all sail set and 'clean full' would go in smooth water from	1 to 2 knots.		
3	Gentle breeze		3 to 4 knots.		
4	Moderate breeze		5 to 6 knots.	Moderate breeze	Forces most advan-tageous for sailing with leading wind and all sail drawing
5	Fresh breeze	That to which she could just carry in chase 'full and by'	Royals, etc.		
6	Strong breeze		Single-reefed top-sails or top-gallant sails.	Strong wind	Reduction of sail necessary with leading wind.
7	Moderate gale (*high wind*) †		Double-reefed topsails, jib, etc.		
8	Fresh gale (*gale*) †		Triple-reefed topsails, etc.	Gale forces	Considerable red tion of sail nec sary even wi wind quartering.
9	Strong gale		Close-reefed top-sails and courses.		
10	Whole gale .	That which she could scarcely bear with close-reefed main top-sail and reefed foresail		Storm forces	Close-reefed sail r ning, or hove under storm-sail
11	Storm . . .	That which would re-duce her to storm stay-sails.			
12	Hurricane .	That which no canvas could withstand.		Hurricane	No sail can stand e when running.

* The fishing smack in this column may be taken as representing a trawler allowance must be made.

† It has recently been decided that for statistical purposes winds of force of the term 'moderate gale' for force 7 the Beaufort description has b of the descriptions in italics for forces 7 and 8.

EQUIVALENTS OF THE NUMBERS OF THE SCALE.

Aeronautics, 1909–10. By Dr. W. N. Shaw, F.R.S.)

Specification of Beaufort Scale. For coast use based on observations made at Scilly, Yarmouth, and Holyhead.	Specification of Beaufort Scale. For use on land, based on observations made at land stations.	Mean wind force in lbs. per sq. ft. at standard density ($P = \cdot 0105\, B^3$).	Equivalent hourly velocity for expressing estimates in miles per hour and vice versa ($V = 1\cdot 87 \sqrt{B^3}$).	Equivalent hourly velocity in knots.
Calm.	Calm, smoke rises vertically.	0	0	0
Fishing smack* just has steerage way.	Direction of wind shown by smoke drift, but not by wind vanes.	·01	2	2
Wind fills the sails of smacks, which then move at about 1–2 miles per hour.	Wind felt on face; leaves rustle; ordinary vane moved by wind.	·08	5	4
Smacks begin to careen and travel about 3–4 miles per hour.	Leaves and small twigs in constant motion; wind extends light flag.	·28	10	9
Good working breeze; smacks carry all canvas with good list.	Raises dust and loose paper; small branches are moved.	·67	15	13
Smacks shorten sail.	Small trees in leaf begin to sway; wavelets form on inland waters.	1·31	21	18
Smacks have double reef in mainsail. Care required when fishing.	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	2·3	27	23
Smacks remain in harbour, and those at sea lie to.	Whole trees in motion; inconvenience felt when walking against wind.	3·6	35	30
All smacks make for harbour if near.	Breaks twigs of trees; generally impedes progress.	5·4	42	37
—	Slight structural damage occurs (chimney-pots and slates removed).	7·7	50	44
—	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	10·5	59	51
—	Very rarely experienced; accompanied by widespread damage.	14·0	68	59
—	—	Above 17·0	Above 75	Above 65

verage type and trim. For larger or smaller boats and for special circumstance

ıan 8 shall not be counted as gales, and to avoid the ambiguity implied by the us
ıodified for use in connection with the daily weather service by the substitutio

TABLE OF DISTANCES DOWN THE COURSE OF THE RIVER THAMES IN NAUTICAL MILES.

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

	London Bridge	Deptford Dockyard Basin	Greenwich, West of College	Blackwall Pier, East End	Woolwich, Roff's Wharf	Barking Creek	Half-way House	Rainham Creek	Erith Pier	Purfleet	Greenhithe Pier	Grays Pier	Gravesend Town Pier	Oven's Buoy	Hope Point	Shell Haven House	Yauntlett Buoy	Abreast of Southend Pier	Nore Light
Deptford Dockyard Basin	3·45																		
Greenwich, West of College	4·15	·70																	
Blackwall Pier, East End	5·77	2·32	1·62																
Woolwich, Roff's Wharf	8·40	4·95	4·25	2·68															
Barking Creek	10·10	6·65	5·95	4·38	1·70														
Half-way House	11·40	7·95	7·25	5·63	3·00	1·30													
Rainham Creek	13·10	9·65	8·95	7·38	4·70	3·00	1·70												
Erith Pier	14·30	10·85	10·15	8·53	5·90	4·20	2·90	1·20											
Purfleet	16·00	12·55	11·85	10·23	7·60	5·90	4·60	2·90	1·70										
Greenhithe Pier	18 60	15·15	14·45	12·83	10·20	8·50	7·20	5·50	4·30	2·60									
Grays Pier	20·40	16·95	16·25	14·63	12·00	10 30	9·00	7·30	6·10	4·40	1·80								
Gravesend Town Pier	22·95	19·50	18·80	17·18	14·55	12·85	11·55	9·85	8·65	6·95	4·35	2·55							
Oven's Buoy	25·80	22·35	21·65	20·03	17·40	15·70	14·40	12·70	11·50	9·80	7·20	5·40	2·85						
Hope Point	27·55	24·10	23·40	21·78	19 15	17·45	16·15	14·45	13·25	11·55	8·95	7·15	4 60	1·75					
Shell Haven House	30·10	26·65	25·95	24·33	21·70	20·00	18·70	17·00	15·80	14·10	11·50	9·70	7·15	4·80	2·55				
Yauntlett Buoy	35·00	31·55	30·85	29·28	26·60	24·90	23 60	21·90	20 70	19·00	16 40	14·60	12·05	9·20	7·45	4·90			
Abreast of Southend Pier	37·90	34·45	33·75	32·18	29·50	27·80	26·50	24·80	23·60	21·90	19·30	17·50	14·95	12·10	10·35	7·80	2·90		
Nore Light	41·60	38·15	37·45	35·88	33·20	31·60	30·20	28·50	27·30	25·60	28·00	21 20	18·65	15·80	14·05	11·50	6·60	8·70	
Sheerness, Garrison Point	45·20	41·75	41·05	39·43	36·80	35·10	33·60	32·10	30·90	29·20	26·60	24·80	23·35	19·40	17·65	15·10	10·20	7·80	8·60

TABLE OF DISTANCES DOWN THE COURSE OF THE RIVER CLYDE IN NAUTICAL MILES.

	Glasgow, Broomielaw Bridge	Finnieston Ferry	Kelvinhaugh Ferry	Govan Ferry	Whiteinch	Renfrew Ferry	Bowling Railway Pier	Dumbarton Castle	Port Glasgow Light	Greenock Pier	Gourock Pier	Cloch Light	Toward Point
Finnieston Ferry .	·87												
Kelvinhaugh Ferry .	1·52	·65											
Govan Ferry . .	1·84	·97	·32										
Whiteinch . .	3·04	2·17	1·52	1·20									
Renfrew Ferry . .	4·45	3·58	2·93	2·61	1·41								
Bowling Railway Pier	9·34	8·47	7·82	7·50	6·30	4·89							
Dumbarton Castle .	11·83	10·96	10·31	9·99	8·79	7·38	2·49						
Port Glasgow Light .	15·96	15·09	14·44	14·12	12·92	11·51	6·62	4·13					
Greenock Pier . .	18·78	17·91	17·26	16·94	15·74	14·33	9·44	6·95	2·82				
Gourock Pier . .	20·84	19·97	19·32	19·00	17·80	16·39	11·50	9·01	4·88	2·06			
Cloch Light . .	23·34	22·47	21·82	21·50	20·30	18·89	14·00	11·51	7·38	4·56	2·50		
Toward Point . .	29·09	28·22	27·57	27·25	26·05	24·64	19·75	17·26	13·13	10·31	8·25	5·75	
Cumbrae Light . .	37·00	36·13	35·48	35·16	33·96	32·55	27·66	25·17	21·04	18·22	16·16	13·66	7·91

The distance between the Cloch and Cumbrae Light is 13·666 knots, or 15·736 statute miles.

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

TABLE OF DISTANCES FROM CARLISLE BRIDGE TO ROCK-A-BILL LIGHT, AND FROM CARLISLE BRIDGE TO WICKLOW HEAD, IN NAUTICAL MILES.

Carlisle Bridge	Carlisle Bridge	North Wall Light	Pool Beg Light	Bailey Light	Howth Harbour Light	Kingstown, E. Pier	Kish Light-vessel
North Wall Light	1·17						
Pool Beg Light	3·97	2·80					
Bailey Light	7·77	6·60	3·80				
Howth Harbour Light	10·57	9·40	6·60	2·80			
Rock-a-Bill Light	22·77	21·60	18·80	15·00	13·20		
Kingstown, E. Pier	6·67	5·50	2·70	4·50	—		
Kish Light-vessel	13·32	12·15	9·35	5·00	—	6·65	
Wicklow Head	34·32	33·15	30·35	—	—	27·65	
Wicklow Head, 2 lights in one, distance 1½ mile	28·17	27·00	24·20	23·92	—	21·50	21·00

The distance from Kingstown (E. Pier) to Holyhead is 56 knots, or 64·48 statute miles.
Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

TABLE OF DISTANCES FROM CUMBERLAND BASIN DOWN THE BRISTOL CHANNEL IN NAUTICAL MILES.

	Cumberland Basin	Lamplighter Slip	King Road, Black Buoy	Portishead Point	Lightship on Welsh and English Grounds	Lightship on Flat Holmes	Black and White Striped Buoy at Breaksea Point	Nash Point, bearing 1 mile N. by E.	West Helwick Sand Light-vessel
Lamplighter Slip	4·0								
King Road, Black Buoy	6·4	2·4							
Portishead Point	8·4	4·4	2·0						
Lightship on Welsh and English Grounds	16·0	12·0	9·6	7·6					
Lightship on Flat Holmes	22·8	18·8	16·4	14·4	6·8				
Foreland Point	49·6	45·6	43·2	41·2	33·6				
Ilfracombe	62·0	58·0	55·6	53·6	46·0				
Black and White Striped Buoy at Breaksea Pt.	33·9	29·9	27·5	25·5	17·9	11·1			
Nash Point, bearing 1 mile N. by E.	39·5	35·5	33·1	31·1	23·5	16·7	5·6		
West Helwick Sand Light-vessel	71·7	67·7	65·3	63·3	55·7	48·9	37·8	32·2	
St. Ann's Head Lighthouse	103·7	99·7	97·3	95·3	87·7	80·9	69·8	64·2	32·0

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

TABLE OF DISTANCES FROM ROCK FERRY, LIVERPOOL, TO HOLYHEAD BREAKWATER IN NAUTICAL MILES.

	Liverpool, Rock Ferry	Rock Lighthouse	Crosby Lightship	Formby Lightship	Bell Beacon	North-west Lightship	North Toe, Great Orme's Head	Point Lynas	Skerries
Rock Lighthouse, No. 5, Red Buoy	4·40								
Crosby Lightship	9·20	4·80							
Formby Lightship	11·80	7·40	2·60						
Bell Beacon	14·10	9·70	4·90	2·30					
North-west Lightship	18·72	14·32	9·52	6·92	4·62				
North Toe, Great Orme's Head	40·72	36·32	31·52	29·92	26·62	22·00			
Point Lynas	56·52	52·12	47·32	44·72	22·42	37·80	15·80		
Point Lynas	55·22	50·82	46·02	43·42	41·12	36·50	—		
Skerries	67·22	62·82	58·02	55·42	53·12	48·50	—	12·00	
Holyhead Breakwater Light	72·82	68·42	63·62	61·02	58·72	54·10	—	17·60	5·60

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

TABLE OF DISTANCES DOWN THE CENTRE OF THE RIVER TYNE IN NAUTICAL MILES.

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

	Tyne Bridge	Tyne Main Shipping Spout	Friar's Goose Point	St. Anthony's Point	Bill Point	Hebburn Quay Road at Leslie's Building Yard	Wallsend Ironworks	Howdon Landing, opposite Palmer's Iron Ship-building Yard	Northumberland Dock Entrance	Jarrow Dock Entrance, opposite side	Whitehill Point, North side	Mill Dam Landing-place, South Shields	New Quay Landing-place, North Shields	Low Lighthouse, North Shields
Tyne Main Shipping Spout . . .	1·09													
Friar's Goose Point	1·44	·35												
St. Anthony's Point	2·20	1·11	·76											
Bill Point	2·70	1·61	1·26	·50										
Hebburn Quay Road at Leslie's Building Yard	4·02	2·93	2·58	1·82	1·32									
Wallsend Ironworks	4·50	3·41	3·06	2·30	1·80	·48								
Howdon Landing, opposite Palmer's Iron Ship-building Yard . .	5·43	4·34	3·99	3·23	2·73	1·41	·93							
Northumberland Dock Entrance . .	6·08	4·99	4·64	3·88	3·38	2·06	1·58	·65						
Jarrow Dock Entrance, opposite side .	6·80	5·71	5·36	4·60	4·10	2·78	2·30	1·37	·72					
Whitehill Point, North side . .	7·03	5·94	5·59	4·83	4·33	3·01	2·53	1·60	·95	·23				
Mill Dam Landing-place, South Shields	7·33	6·24	5·89	5·13	4·63	3·31	2·83	1·90	1·25	·53	·30			
New Quay Landing-place, North Shields	7·80	6·71	6·36	5·60	5·10	3·78	3·30	2·37	1·72	1·00	·77	·47		
Low Lighthouse, North Shields . .	8·20	7·11	6·76	6·00	5·50	4·18	3·70	2·77	2·12	1·40	1·17	·87	·40	
Tynemouth Bar	8·96	7·87	7·52	6·76	6·26	4·94	4·46	3·53	2·88	2·16	1·93	1·63	1·16	·76

The distance from Tynemouth Bar to New Biggen Point is 13·32 statute miles, or 11·57 knots

TABLE OF DISTANCES DOWN THE RIVER HUMBER, BY SHIP'S CHANNEL COURSE, FROM HULL ROADS TO SEA IN NAUTICAL MILES.

	Hull Roads, Citadel bearing N.	Hebble's Float	No. 7, Red Buoy	No. 10, Black Buoy	No. 9, Black Buoy	No. 8, Black Buoy	No. 6, Black Buoy	No. 3, Chequered Buoy	No. 3, Red Buoy	Bull Float	No. 1, Chequered Buoy
Hebble's Float	1·51										
No. 7, Red Buoy, or Paul Lighthouse, N.E. by E.	3·69	2·18									
No. 10, Black Buoy	6·08	4·57	2·39								
No. 9, Black Buoy, or Killingholme High Light, W. by S.	7·38	5·87	3·69	1·30							
No. 8, Black Buoy	9·12	7·61	5·43	3·04	1·74						
No. 6, Black Buoy	11·51	10·00	7·82	5·43	4·13	2·39					
No. 3, Chequered Buoy, or Grimsby Hydraulic Tower, W. by S.	14·54	13·03	10·85	8·46	7·16	5·42	3·03				
No. 3, Red Buoy	16·72	15·21	13·03	10·64	9·34	7·60	5·21	2·18			
Bull Float, or Spurn High Light, E.N.E.	19·32	17·81	15·63	13·24	11·94	10·20	7·81	4·78	2·60		
No. 1, Chequered Buoy	21·93	20·42	18·24	15·85	14·55	12·81	10·42	7·39	5·21	6·21	
Newsand Float, N.E.	23·66	22·15	19·97	17·58	16·28	14·54	12·15	9·12	6·94	4·34	1·73

The distance between No. 8, Black Buoy, and Spurn High Light, E.N.E. 1 mile, is 10·2 knots, or 11·5 statute miles.

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

TABLE OF DISTANCES FROM CARRIGALOE FERRY TO ROCHE POINT, AND FROM ROCHE POINT TO DUNMORE ON THE EAST AND TO FASTNET ON THE WEST, IN NAUTICAL MILES.

Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

	Carrigaloe Ferry	Black Buoy	Bar Rock	Abreast of Dognose	Lighthouse, Roche Point	Poor Head	Ballycotton	Capel Island	Ram Head	Minehead	Buoy on Daunt's Rock	Kinsale Head Light	Seven Heads	Stags
Black Buoy opposite Haulbowline	2·20													
Bar Rock, midway between Black and White Buoy . .	3·70	1·50												
Abreast of Dognose . . .	5·90	3·70	2·20											
Abreast of Lighthouse on Roche Pt.	7·30	5·10	3·60	1·40										
Poor Head, distant 1 mile . .	11·14	8·94	7·44	5·24	3·84									
Ballycotton, distant 1 mile . .	18·81	16·61	15·11	12·91	11·51	7·67								
Capel Island (Knockadoon), distant 1 mile N.	24·81	22·61	21·11	18·91	17·51	13·67	6·00							
Tower on Ram Head, distant 1 m. N.	31·12	28·92	27·42	25·22	23·82	19·98	12·31	6·31						
Minehead Light, distant 1 mile N.	36·62	34·42	32·92	30·72	29·32	25·48	17·81	11·81	5·50					
Dunmore (Waterford) Light, distant 1 mile N. . .	60·74	58·54	57·04	54·84	53·44	49·60	41·93	35·93	29·62	24·12				
Buoy on Daunt's Rock (Robert's Head), distant 1 mile N. .	12·50	10·30	8·80	6·60	—	—	—	—	—	—				
Kinsale Head Light, distant 1 m. N.	24·00	21·80	20·30	18·10	—	—	—	—	—	—	11·50			
Seven Heads, distant 1¼ mile N. .	31·00	28·80	27·30	25·10	—	—	—	—	—	—	18·50	7·00		
Stags (Toe Head), distant 1 mile N.	51·60	49·40	47·90	45·70	—	—	—	—	—	—	39·10	27·60	20·60	
Fastnet Light	66·60	64·40	62·90	60·70	—	—	—	—	—	—	54·10	42·60	35·60	15·00

TABLE OF DISTANCES FROM DEVONPORT STEAM BRIDGE TO PLYMOUTH BREAKWATER, AND FROM THE BREAKWATER TO THE LIZARD WEST AND PORTLAND BILL EAST, IN NAUTICAL MILES.

	Devonport Steam Bridge	Block House	Asia White Buoy	Breakwater Light	Red and White Chequered Buoy	Beacon, East End of Breakwater	Little Mewstone	Bolt Head	Praul Point	Start Point
Block House, Devil's Point	1·60									
Asia White Buoy	2·60	1·00								
Breakwater Light, 1 cable-length W. by N.	4·60	3·00	2·00							
Red and White Chequered Buoy on Dray Stone	6·00	4·40	3·40	1·40						
Lizard, distant 2 miles N.	51·75	50·15	49·15	47·15	45·75					
Beacon, East End of Breakwater	4·20	2·60	1·60	—	—					
Little Mewstone, distant 3 cables East	6·20	4·60	3·60	—	—	2·00				
Bolt Head, distant 1 mile N.	20·70	19·10	18·10	—	—	16·50	14·50			
Praul Point, distant 1 mile N.	23·70	22·10	21·10	—	—	19·50	17·50	3·00		
Start Point, distant 1 mile N.	27·03	25·43	24·43	—	—	22·83	20·83	6·33	3·33	
Portland Bill, distant 2 miles N.	75·03	73·43	72·43	—	—	70·83	68·83	54·33	51·33	48·00

The distance from Plymouth Breakwater Light to the Eddystone Light is 10·156 knots, or 11·695 statute miles.
Note.—The nautical mile given in this table is the Admiralty knot of 6,080 lineal feet.

WEIGHTS AND DIMENSIONS OF MATERIALS.

Tons × 2240 = lbs. Tons × 20 = cwts. Lbs. × ·000446428 = tons.

Weight of Round or Elliptical Bars.

Diameter × diameter × length in feet × constant = weight in lbs.

Weight of Square or Rectangular Bars.

Width × thickness × length in feet × constant = weight in lbs.

Weight of Plating or Planking.

Thickness × breadth in feet × length in feet × constant = weight in lbs.

VALUES OF CONSTANTS FOR ROUND OR ELLIPTICAL BARS.

Material	Diameters taken in					
	Ins.	½ In.	¼ In.	⅛ In.	$\frac{1}{16}$ In.	$\frac{1}{32}$ In.
Brass, sheet . .	2·905980	·726495	·181624	·045406	·011351	·002838
Iron, wrought . .	2·61800	·654500	·163625	·040906	·010227	·002557
Lead, sheet . .	3·88773	·971933	·242983	·060746	·015186	·003797
Steel, soft . . .	2·67036	·667590	·166898	·041724	·010431	·002608
Elm, American . .	·261800	·065450	·016363	·004091	·001023	·000256
Mahogany, Honduras	·196350	·049088	·012272	·003068	·000767	·000192
„ Spanish .	·287980	·071995	·017999	·004500	·001125	·000281
Oak, Dantzic . .	·261800	·065450	·016363	·004091	·001023	·000256
„ English . .	·307615	·076904	·019228	·004807	·001202	·000300
Pine, red . . .	·196350	·049088	·012272	·003068	·000767	·000192
„ yellow . .	·157080	·039270	·009818	·002454	·000614	·000153
Teak, Indian . .	·287980	·071995	·017999	·004500	·001125	·000281

VALUES OF CONSTANTS FOR SQUARE OR RECTANGULAR BARS.

Material	Width and Thickness taken in					
	Ins.	½ In.	¼ In.	⅛ In.	$\frac{1}{16}$ In.	$\frac{1}{32}$ In.
Brass, sheet . .	3·70000	·925000	·231250	·057813	·014453	·003613
Iron, wrought . .	3·33333	·833333	·208333	·052083	·013021	·003255
Lead, sheet . .	4·95000	1·23750	·309375	·077344	·019336	·004834
Steel, soft . . .	3·40000	·850000	·212500	·053125	·013281	·003320
Elm, American . .	·333333	·083333	·020833	·005208	·001302	·000326
Mahogany, Honduras	·250000	·062500	·015625	·003906	·000977	·000244
„ Spanish .	·366667	·091667	·022917	·005729	·001432	·000358
Oak, Dantzic . .	·333333	·083333	·020833	·005208	·001202	·000326
„ English . .	·391667	·097917	·024479	·006120	·001530	·000382
Pine, red . . .	·250000	·062500	·015625	·003906	·000977	·000244
„ yellow . .	·200000	·050000	·012500	·003125	·000781	·000195
Teak, Indian . .	·366667	·091667	·022917	·005729	·001432	·000358

VALUES OF CONSTANTS FOR PLATING OR PLANKING.

Material	Thickness taken in						
	Ins.	½ In.	¼ In.	⅛ In.	$\frac{1}{16}$ In.	$\frac{1}{32}$ In.	$\frac{1}{64}$ In.
Brass, sheet . .	44·4	22·2	11·100	5·550	2·7750	1·38750	·69375
Iron, wrought . .	40·0	20·0	10·000	5·000	2·5000	1·25000	·62500
Lead, sheet . .	59·4	29·7	14·85	7·425	3·7125	1·85625	·92813
Steel, soft . . .	40·8	20·4	10·20	5·100	2·5500	1·27500	·63750
Elm, American . .	4·00	2·00	1·000	·5000	·25000	·12500	·62500
Mahogany, Honduras	3·00	1·50	·750	·3750	·18750	·09375	·04688
„ Spanish .	4·40	2·20	1·100	·5500	·27500	·13750	·06875
Oak, Dantzic . .	4·00	2·00	1·000	·5000	·25000	·125000	·06250
„ English . .	4·70	2·35	1·175	·5875	·29375	·14688	·07344
Pine, red . . .	3·00	1·50	·750	·3750	·18750	·09375	·04688
„ yellow . .	2·40	1·20	·600	·3000	·15000	·07500	·03750
Teak, Indian . .	4·40	2·20	1·100	·5500	·27500	·13750	·06875

WEIGHT OF PIPES.

W = weight per lineal foot in lbs. D = outside diameter in ins.
K = constant from below. d = inside „ „

$$W = (D^2 - d^2)K.$$

Values of K *for Pipes.*

Brass = 2·9060.	Iron, cast = 2·4282.	Lead = 3·8877.
Copper = 2·9943.	„ wrought = 2·6180.	Steel = 2·6704.

WEIGHT OF ANGLE IRON.

W = weight in lbs. per lineal foot. S = sum of the widths of flanges in ins.
T = thickness of flanges in ins.

$$W = T(S - T)\ 3·33333.$$

RELATIVE WEIGHTS OF DIFFERENT SUBSTANCES.

Wrought iron = 1.

Brass, sheet	= 1·1100.	Beech	= ·0896.	Oak, English	= ·1175.
Copper „	= 1·1438.	Elm	= ·1000.	Pine, red	= ·0750.
Iron, cast	= ·9275.	Fir, spruce	= ·0833.	„ yellow	= ·0600.
Lead, sheet	= 1·4850.	Mahogany, Honduras	= ·0750.	Sycamore	= ·0808.
Steel, soft	= 1·0200.	„ Spanish	= ·1100.	Teak, African	= ·1145.
Tin	= ·9500.	Maple	= ·1021.	„ Indian	= ·1277.
Zinc	= ·9494.	Oak, Dantzic	= ·1000.	Willow	= ·0521.

WEIGHT, &c., OF FRESH WATER.

A cubic foot	= ·0279 ton	= 62·39 lbs.	= 998·18 avd. ozs.	= 6·2321 galls.
A cubic inch	= ·0361 lb.	= ·5776 avd. oz.	= ·0036 gall.	
A gallon	= ·0045 ton	= 10·000 lbs.	= 160·15 avd. ozs.	= ·16044 cu. ft.
A ton	= 35·905 cu. ft.	= 2240 lbs.	= 223·76 galls.	

Weight of fresh water = weight of salt water × ·9740.

WEIGHT, &c., OF SALT WATER.

A cubic foot	= ·0286 ton	= 64·05 lbs.	= 1024·80 avd. ozs.	= 6·2321 galls.
A cubic inch	= ·0371 lb.	= ·5930 avd. oz.	= ·0036 gall.	
A gallon	= ·0046 ton	= 10·276 lbs.	= 164·41 avd. ozs.	= ·16044 cu. ft.
A ton	= 34·973 cu. ft.	= 2240 lbs.	= 217·95 galls.	

Note.—A cubic foot of salt water is usually taken at 35 cu. ft. to the ton and 64 lbs. to the cubic foot, fresh water being taken at 36 cu. ft. to the ton and 62·25 lbs. to the cubic foot.

MISCELLANEOUS FACTORS.

A ton	= 1·01605 tonne or tonneau.
An avd. lb.	= ·45359 kilogram.
A foot	= ·304797 metre.
A sq. foot	= ·092901 sq. metre.
A sq. inch	= 645·148 sq. millimetres.
A cu. ft.	= ·028316 cu. metre.
A cubic yard	= ·764534 cu. metre.
A mile	= 1·60933 kilometre.
Knot per hour	= 1·688 foot per second.
„ „	= ·5144 metre per second.
Mile per hour	= 1·467 foot per second.
A gallon	= 4·54102 litres.
A tonne or tonneau	= ·984206 ton.
A kilogram	= 2·20462 lbs.
A metre	= 3·2808693 feet.
A sq. metre	= 10·7641 sq. feet.
A sq. millimetre	= ·00155003 sq. in.
A cubic metre	= 35·3156 cu. feet.
„ „	= 1·30799 cu. yd.
A kilometre	= ·621377 mile.
Foot per second	= ·592 knot per hour.
Metre per second	= 1·944 knot per hour.
Foot per second	= ·682 mile per hour.
A litre	= ·220215 gallon.

Table of the Weight of Malleable Flat Steel in Lbs. per Lineal Foot.

Breadth of Plate (ins.)	Thickness in Fractions of an Inch.																				Breadth of Plate (ins.)
	$\frac{1}{20}$	$\frac{2}{20}$	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	
1	·17	·34	·51	·68	·85	1·02	1·19	1·36	1·53	1·70	1·87	2·04	2·21	2·38	2·55	2·72	2·89	3·06	3·23	3·40	1
1¼	·21	·43	·64	·85	1·06	1·28	1·49	1·70	1·91	2·13	2·34	2·55	2·76	2·98	3·19	3·40	3·61	3·83	4·04	4·25	1¼
1½	·26	·51	·77	1·02	1·28	1·53	1·79	2·04	2·30	2·55	2·81	3·06	3·32	3·57	3·83	4·08	4·34	4·59	4·85	5·10	1½
1¾	·30	·60	·89	1·19	1·49	1·79	2·08	2·38	2·68	2·98	3·27	3·57	3·87	4·17	4·46	4·76	5·06	5·36	5·65	5·95	1¾
2	·34	·68	1·02	1·36	1·70	2·04	2·38	2·72	3·06	3·40	3·74	4·08	4·42	4·76	5·10	5·44	5·78	6·12	6·46	6·80	2
2¼	·38	·77	1·15	1·53	1·91	2·30	2·68	3·06	3·44	3·83	4·21	4·59	4·97	5·36	5·74	6·12	6·50	6·89	7·27	7·65	2¼
2½	·43	·85	1·28	1·70	2·13	2·55	2·98	3·40	3·83	4·25	4·68	5·10	5·53	5·95	6·38	6·80	7·23	7·65	8·08	8·50	2½
2¾	·47	·94	1·40	1·87	2·34	2·81	3·27	3·74	4·21	4·68	5·14	5·61	6·08	6·55	7·01	7·48	7·95	8·42	8·88	9·35	2¾
3	·51	1·02	1·53	2·04	2·55	3·06	3·57	4·08	4·59	5·10	5·61	6·12	6·63	7·14	7·65	8·16	8·67	9·18	9·69	10·20	3
3¼	·55	1·11	1·66	2·21	2·76	3·32	3·87	4·42	4·97	5·53	6·08	6·63	7·18	7·74	8·29	8·84	9·39	9·95	10·50	11·05	3¼
3½	·60	1·19	1·79	2·38	2·98	3·57	4·17	4·76	5·36	5·95	6·55	7·14	7·74	8·33	8·93	9·52	10·12	10·71	11·31	11·90	3½
3¾	·64	1·28	1·91	2·55	3·19	3·83	4·46	5·10	5·74	6·38	7·01	7·65	8·29	8·93	9·56	10·20	10·84	11·48	12·11	12·75	3¾
4	·68	1·36	2·04	2·72	3·40	4·08	4·76	5·44	6·12	6·80	7·48	8·16	8·84	9·52	10·20	10·88	11·56	12·24	12·92	13·60	4
4¼	·72	1·45	2·17	2·89	3·61	4·34	5·06	5·78	6·50	7·23	7·95	8·67	9·39	10·12	10·84	11·56	12·28	13·01	13·73	14·45	4¼
4½	·77	1·53	2·30	3·06	3·83	4·59	5·36	6·12	6·89	7·65	8·42	9·18	9·95	10·71	11·48	12·24	13·01	13·77	14·54	15·30	4½
4¾	·81	1·62	2·42	3·23	4·04	4·85	5·65	6·46	7·27	8·08	8·88	9·69	10·50	11·31	12·11	12·92	13·73	14·54	15·34	16·15	4¾
5	·85	1·70	2·55	3·40	4·25	5·10	5·95	6·80	7·65	8·50	9·35	10·20	11·05	11·90	12·75	13·60	14·45	15·30	16·15	17·00	5
5¼	·89	1·79	2·68	3·57	4·46	5·36	6·25	7·14	8·03	8·93	9·82	10·71	11·60	12·50	13·39	14·28	15·17	16·07	16·96	17·85	5¼
5½	·94	1·87	2·81	3·74	4·68	5·61	6·55	7·48	8·42	9·35	10·29	11·22	12·16	13·09	14·03	14·96	15·90	16·83	17·77	18·70	5½
5¾	·98	1·96	2·93	3·91	4·89	5·87	6·84	7·82	8·80	9·78	10·75	11·73	12·71	13·69	14·66	15·64	16·62	17·60	18·57	19·55	5¾
6	1·02	2·04	3·06	4·08	5·10	6·12	7·14	8·16	9·18	10·20	11·22	12·24	13·26	14·28	15·30	16·32	17·34	18·36	19·38	20·40	6
Breadth of Plate (ins.)	$\frac{1}{20}$	$\frac{2}{20}$	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{10}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	Breadth of Plate (ins.)
	Thickness in Fractions of an Inch.																				

TABLE OF THE WEIGHT OF MALLEABLE FLAT STEEL IN LBS. PER LINEAL FOOT (concluded).

Breadth of Plate (ins.)	Thickness in Fractions of an Inch.																				Breadth of Plate (ins.)
	1/20	2/20	3/20	4/20	5/20	6/20	7/20	8/20	9/20	10/20	11/20	12/20	13/20	14/20	15/20	16/20	17/20	18/20	19/20	20/20	
6¼	1·06	2·13	3·19	4·25	5·31	6·38	7·44	8·50	9·56	10·63	11·69	12·75	13·81	14·88	15·94	17·00	18·06	19·13	20·19	21·25	6¼
6½	1·11	2·21	3·32	4·42	5·53	6·63	7·74	8·84	9·95	11·05	12·16	13·26	14·37	15·47	16·58	17·68	18·79	19·89	21·00	22·10	6½
6¾	1·15	2·30	3·44	4·59	5·74	6·89	8·03	9·18	10·33	11·48	12·62	13·77	14·92	16·07	17·21	18·36	19·51	20·66	21·80	22·95	6¾
7	1·19	2·38	3·57	4·76	5·95	7·14	8·33	9·52	10·71	11·90	13·09	14·28	15·47	16·66	17·85	19·04	20·23	21·42	22·61	23·80	7
7¼	1·23	2·47	3·70	4·93	6·16	7·40	8·63	9·86	11·09	12·33	13·56	14·79	16·02	17·26	18·49	19·72	20·95	22·19	23·42	24·65	7¼
7½	1·28	2·55	3·83	5·10	6·38	7·65	8·93	10·20	11·48	12·75	14·03	15·30	16·58	17·85	19·13	20·40	21·68	22·95	24·23	25·50	7½
7¾	1·32	2·64	3·95	5·27	6·59	7·91	9·22	10·54	11·86	13·18	14·49	15·81	17·12	18·45	19·76	21·08	22·40	23·72	25·03	26·35	7¾
8	1·36	2·72	4·08	5·44	6·80	8·16	9·52	10·88	12·24	13·60	14·96	16·32	17·68	19·04	20·40	21·76	23·12	24·48	25·84	27·20	8
8¼	1·40	2·81	4·21	5·61	7·01	8·42	9·82	11·22	12·62	14·03	15·43	16·83	18·23	19·64	21·04	22·44	23·84	25·25	26·65	28·05	8¼
8½	1·45	2·89	4·34	5·78	7·23	8·67	10·12	11·56	13·01	14·45	15·90	17·34	18·79	20·23	21·68	23·12	24·57	26·01	27·46	28·90	8½
8¾	1·49	2·98	4·46	5·95	7·44	8·93	10·41	11·90	13·39	14·88	16·36	17·85	19·34	20·83	22·31	23·80	25·29	26·78	28·26	29·75	8¾
9	1·53	3·06	4·59	6·12	7·65	9·18	10·71	12·24	13·77	15·30	16·83	18·36	19·89	21·42	22·95	24·48	26·01	27·54	29·07	30·60	9
9¼	1·57	3·15	4·72	6·29	7·86	9·44	11·01	12·58	14·15	15·73	17·30	18·87	20·44	22·02	23·59	25·16	26·73	28·31	29·88	31·45	9¼
9½	1·62	3·23	4·85	6·46	8·08	9·69	11·31	12·92	14·54	16·15	17·77	19·38	21·00	22·61	24·23	25·84	27·46	29·07	30·69	32·30	9½
9¾	1·66	3·32	4·97	6·63	8·29	9·95	11·60	13·26	14·92	16·58	18·23	19·89	21·55	23·21	24·86	26·52	28·18	29·84	31·49	33·15	9¾
10	1·70	3·40	5·10	6·80	8·50	10·20	11·90	13·60	15·30	17·00	18·70	20·40	22·10	23·80	25·50	27·20	28·90	30·60	32·30	34·00	10
10¼	1·74	3·49	5·23	6·97	8·71	10·46	12·20	13·94	15·68	17·43	19·17	20·91	22·65	24·40	26·14	27·88	29·62	31·37	33·11	34·85	10¼
10½	1·79	3·57	5·36	7·14	8·93	10·71	12·50	14·28	16·07	17·85	19·64	21·42	23·21	24·99	26·78	28·56	30·35	32·13	33·92	35·70	10½
11	1·87	3·74	5·61	7·48	9·35	11·22	13·09	14·96	16·83	18·70	20·57	22·44	24·31	26·18	28·05	29·92	31·79	33·66	35·52	37·40	11
11½	1·96	3·91	5·87	7·82	9·78	11·73	13·69	15·64	17·60	19·55	21·51	23·46	25·42	27·37	29·33	31·28	33·24	35·19	37·15	39·10	11½
12	2·04	4·08	6·12	8·16	10·20	12·24	14·28	16·32	18·36	20·40	22·44	24·48	26·52	28·56	30·60	32·64	34·68	36·72	38·76	40·80	12
Breadth of Plate (ins.)	1/20	2/20	3/20	4/20	5/20	6/20	7/20	8/20	9/20	10/20	11/20	12/20	13/20	14/20	15/20	16/20	17/20	18/20	19/20	20/20	Breadth of Plate (ins.)
	Thickness in Fractions of an Inch.																				

Table of the Weight of Angle and T Steel in Lbs. per Lineal Foot.

Sum of Flanges (ins.)	Thickness in Fractions of an Inch.																	Sum of Flanges (ins.)
	$\frac{1}{20}$	$\frac{2}{20}$	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	
1	·162	·306	·434	·544	·638	—	—	—	—	—	—	—	—	—	—	—	—	1
$1\frac{1}{4}$	·204	·391	·561	·714	·850	—	—	—	—	—	—	—	—	—	—	—	—	$1\frac{1}{4}$
$1\frac{1}{2}$	·247	·476	·689	·884	1·063	1·244	—	—	—	—	—	—	—	—	—	—	—	$1\frac{1}{2}$
$1\frac{3}{4}$	·289	·561	·816	1·054	1·275	1·479	1·67	—	—	—	—	—	—	—	—	—	—	$1\frac{3}{4}$
2	·332	·646	·944	1·224	1·488	1·734	1·96	—	—	—	—	—	—	—	—	—	—	2
$2\frac{1}{4}$	·374	·731	1·071	1·394	1·700	1·989	2·36	2·52	—	—	—	—	—	—	—	—	—	$2\frac{1}{4}$
$2\frac{1}{2}$	·417	·816	1·199	1·564	1·913	2·244	2·56	2·86	—	—	—	—	—	—	—	—	—	$2\frac{1}{2}$
$2\frac{3}{4}$	·459	·901	1·326	1·734	2·125	2·499	2·86	3·20	3·52	—	—	—	—	—	—	—	—	$2\frac{3}{4}$
3	·502	·986	1·454	1·904	2·338	2·754	3·15	3·54	3·90	4·25	—	—	—	—	—	—	—	3
$3\frac{1}{4}$	·544	1·071	1·581	2·074	2·550	3·009	3·45	3·88	4·28	4·68	—	—	—	—	—	—	—	$3\frac{1}{4}$
$3\frac{1}{2}$	·587	1·156	1·709	2·244	2·763	3·264	3·75	4·22	4·67	5·10	5·52	—	—	—	—	—	—	$3\frac{1}{2}$
$3\frac{3}{4}$	·629	1·241	1·836	2·414	2·975	3·519	4·05	4·56	5·05	5·53	5·98	—	—	—	—	—	—	$3\frac{3}{4}$
4	·672	1·326	1·964	2·584	3·188	3·774	4·34	4·90	5·43	5·95	6·45	6·94	—	—	—	—	—	4
$4\frac{1}{4}$	·714	1·411	2·091	2·754	3·400	4·029	4·64	5·24	5·81	6·38	6·92	7·45	7·96	—	—	—	—	$4\frac{1}{4}$
$4\frac{1}{2}$	·757	1·496	2·219	2·924	3·613	4·284	4·94	5·58	6·20	6·80	7·39	7·96	8·51	—	—	—	—	$4\frac{1}{2}$
$4\frac{3}{4}$	·799	1·581	2·346	3·094	3·825	4·539	5·24	5·92	6·58	7·23	7·85	8·47	9·06	9·64	—	—	—	$4\frac{3}{4}$
5	·842	1·666	2·474	3·264	4·038	4·794	5·53	6·26	6·96	7·65	8·32	8·98	9·61	10·23	10·84	—	—	5
$5\frac{1}{4}$	·884	1·751	2·601	3·434	4·250	5·049	5·83	6·60	7·34	8·08	8·79	9·49	10·17	10·83	11·48	—	—	$5\frac{1}{4}$
$5\frac{1}{2}$	·927	1·836	2·729	3·604	4·463	5·304	6·13	6·94	7·73	8·50	9·26	10·00	10·72	11·42	12·11	12·78	—	$5\frac{1}{2}$
$5\frac{3}{4}$	·969	1·921	2·856	3·774	4·675	5·559	6·43	7·28	8·11	8·98	9·72	10·51	11·27	12·02	12·75	13·46	14·16	$5\frac{3}{4}$

TABLE OF THE WEIGHT OF ANGLE AND T STEEL IN LBS. PER LINEAL FOOT (continued).

Sum of Flanges (ins.)	Thickness in Fractions of an Inch.																		Sum of Flanges (ins.)
	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	
6	2·98	3·94	4·89	5·81	6·72	7·62	8·49	9·35	10·19	11·02	11·82	12·61	13·39	14·14	14·88	—	—	—	6
$6\frac{1}{4}$	3·11	4·11	5·10	6·07	7·02	7·96	8·87	9·78	10·66	11·53	12·38	13·21	14·03	14·82	15·61	—	—	—	$6\frac{1}{4}$
$6\frac{1}{2}$	3·24	4·28	5·31	6·32	7·32	8·30	9·26	10·20	11·13	12·04	12·93	13·80	14·66	15·50	16·33	17·14	—	—	$6\frac{1}{2}$
$6\frac{3}{4}$	3·37	4·45	5·53	6·58	7·62	8·64	9·64	10·63	11·59	12·55	13·48	14·40	15·30	16·18	17·05	17·90	—	—	$6\frac{3}{4}$
7	3·49	4·62	5·74	6·83	7·91	8·98	10·02	11·05	12·06	13·06	14·03	14·99	15·94	16·86	17·77	18·67	19·54	—	7
$7\frac{1}{4}$	3·62	4·79	5·95	7·09	8·21	9·32	10·40	11·48	12·53	13·57	14·59	15·59	16·58	17·54	18·50	19·43	20·35	—	$7\frac{1}{4}$
$7\frac{1}{2}$	3·75	4·96	6·16	7·34	8·51	9·66	10·79	11·90	13·00	14·08	15·14	16·18	17·21	18·22	19·22	20·20	21·16	22·10	$7\frac{1}{2}$
$7\frac{3}{4}$	3·88	5·13	6·38	7·60	8·81	10·00	11·17	12·33	13·46	14·59	15·69	16·78	17·85	18·90	19·94	20·96	21·96	22·95	$7\frac{3}{4}$
8	4·00	5·30	6·59	7·85	9·10	10·34	11·55	12·75	13·93	15·10	16·24	17·37	18·49	19·58	20·66	21·73	22·77	23·80	8
$8\frac{1}{4}$	4.13	5·47	6·80	8·11	9·40	10·68	11·93	13·18	14·40	15·61	16·80	17·97	19·13	20·26	21·39	22·49	23·58	24·65	$8\frac{1}{4}$
$8\frac{1}{2}$	4·26	5·64	7·01	8·36	9·70	11·02	12·32	13·60	14·87	16·12	17·35	18·56	19·76	20·94	22·11	23·26	24·39	25·50	$8\frac{1}{2}$
$8\frac{3}{4}$	4·39	5·81	7·23	8·62	10·00	11·36	12·70	14·03	15·33	16·63	17·90	19·16	20·40	21·62	22·83	24·02	25·19	26·35	$8\frac{3}{4}$
9	4·51	5·98	7·44	8·87	10·29	11·70	13·08	14·45	15·80	17·14	18·45	19·75	21·04	22·30	23·55	24·79	26·00	27·20	9
Sum of Flanges (ins.)	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	Sum of Flanges (ins.)
	Thickness in Fractions of an Inch.																		

TABLE OF THE WEIGHT OF ANGLE AND T STEEL IN LBS. PER LINEAL FOOT (continued).

Sum of Flanges (ins.)	Thickness in Fractions of an Inch.																		Sum of Flanges (ins.)
	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	
9¼	4·6	6·15	7·65	9·13	10·59	12·04	13·46	14·88	16·27	17·65	19·01	20·35	21·68	22·98	24·28	25·55	26·81	28·05	9¼
9½	4·77	6·32	7·86	9·38	10·89	12·38	13·85	15·30	16·74	18·16	19·56	20·94	22·31	23·66	25·00	26·32	27·62	28·90	9½
9¾	4·90	6·49	8·03	9·64	11·19	12·72	14·23	15·73	17·20	18·67	20·11	21·54	22·95	24·34	25·72	27·08	28·42	29·75	9¾
10	5·02	6·66	8·29	9·89	11·48	13·06	14·61	16·15	17·67	19·18	20·66	22·13	23·59	25·02	26·44	27·85	29·23	30·60	10
10¼	5·15	6·83	8·50	10·15	11·78	13·40	14·99	16·58	18·14	19·69	21·22	22·73	24·23	25·70	27·17	28·61	30·04	31·45	10¼
10½	5·28	7·00	8·71	10·40	12·08	13·74	15·38	17·00	18·61	20·20	21·77	23·32	24·86	26·38	27·89	29·38	30·85	32·30	10½
10¾	5·41	7·17	8·93	10·66	12·38	14·08	15·76	17·43	19·07	20·71	22·32	23·92	25·50	27·06	28·61	30·14	31·65	33·15	10¾
11	5·53	7·34	9·14	10·91	12·67	14·42	16·14	17·85	19·54	21·22	22·87	24·51	26·14	27·74	29·33	30·91	32·46	34·00	11
11¼	5·66	7·51	9·35	11·17	12·97	14·76	16·52	18·28	20·01	21·73	23·43	25·11	26·78	28·42	30·06	31·67	33·27	34·85	11¼
11½	5·79	7·68	9·56	11·42	13·27	15·10	16·91	18·70	20·48	22·24	23·98	25·70	27·41	29·10	30·78	32·44	34·08	35·70	11½
11¾	—	7·85	9·78	11·68	13·57	15·44	17·29	19·13	20·94	22·75	24·53	26·30	28·05	29·78	31·50	33·20	34·88	36·55	11¾
12	—	8·02	9·99	11·93	13·86	15·78	17·67	19·55	21·41	23·26	25·08	26·89	28·69	30·46	32·22	33·97	35·69	37·40	12
12¼	—	8·19	10·20	12·19	14·16	16·12	18·05	19·98	21·88	23·77	25·64	27·49	29·33	31·14	32·95	34·73	36·50	38·25	12¼
Sum of Flanges (ins.)	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	Sum of Flanges (ins.)
	Thickness in Fractions of an Inch.																		

TABLE OF THE WEIGHT OF ANGLE AND T STEEL IN LBS. PER LINEAL FOOT (concluded).

Sum of Flanges (ins.)	$\frac{3}{20}$	$\frac{4}{20}$	$\frac{5}{20}$	$\frac{6}{20}$	$\frac{7}{20}$	$\frac{8}{20}$	$\frac{9}{20}$	$\frac{10}{20}$	$\frac{11}{20}$	$\frac{12}{20}$	$\frac{13}{20}$	$\frac{14}{20}$	$\frac{15}{20}$	$\frac{16}{20}$	$\frac{17}{20}$	$\frac{18}{20}$	$\frac{19}{20}$	$\frac{20}{20}$	Sum of Flanges (ins.)
$12\frac{1}{2}$	—	8·36	10·41	12·44	14·48	16·46	18·44	20·40		24·28	26·19	28·08	29·96					39·10	$12\frac{1}{2}$
$12\frac{3}{4}$	—	—	10·63	12·70	14·76	16·80	18·82	20·83		24·79	26·74	28·68	30·60					39·95	$12\frac{3}{4}$
13	—	—	10·84	12·95	15·05	17·14	19·20	21·25		25·30	27·29	29·27	31·24					40·80	13
$13\frac{1}{4}$	—	—	11·05	13·21	15·35	17·48	19·58	21·68		25·81	27·85	29·87	31·88					41·65	$13\frac{1}{4}$
$13\frac{1}{2}$	—	—	11·26	13·46	15·65	17·82	19·97	22·10		26·32	28·40	30·46	32·51					42·50	$13\frac{1}{2}$
$13\frac{3}{4}$	—	—	11·48	13·72	15·95	18·16	20·35	22·53		26·83	28·95	31·06	33·15					43·35	$13\frac{3}{4}$
14	—	—	—	13·97	16·24	18·50	20·73	22·95		27·34	29·50	31·65	33·79					44·20	14
$14\frac{1}{4}$	—		—	14·23	16·54	18·84	21·11	23·38		27·85	30·06	32·25	34·43					45·05	$14\frac{1}{4}$
$14\frac{1}{2}$	—		—	14·48	16·84	19·18	21·50	23·80		28·36	30·61	32·84	35·06					45·90	$14\frac{1}{2}$
$14\frac{3}{4}$	—	—	—	14·74	17·14	19·52	21·88	24·23		28·87	31·16	33·44	35·70					46·75	$14\frac{3}{4}$
15	—	—	—	—	17·43	19·86	22·26	24·65		29·38	31·71	34·03	36·34					47·60	15

Thickness in Fractions of an Inch.

RULE.—*To Calculate the Weight of Angle bars:—*
w = weight of metal in lbs. per square foot of t thickness.
t = thickness of angle bar in decimals of a foot.
W = weight of angle bar in lbs. per lineal foot.
S = sum of breadth of flanges in decimals of a foot.
$W = (S - t)w$.

TABLE OF THE WEIGHT OF SHEET METALS OF VARIOUS THICKNESSES IN LBS. PER SQUARE FOOT.

Kind of Metal	Thickness in 16ths of an Inch															
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1 in.
Iron . .	2·5	5·0	7·5	10·0	12·5	15·0	17·5	20·0	22·5	25·0	27·5	30·0	32·5	35·0	37·5	40·0
Steel .	2·55	5·10	7·65	10·20	12·75	15·30	17·85	20·40	22·95	25·50	28·05	30·60	33·15	35·70	38·25	40·80
Brass .	2·78	5·50	8·33	11·10	13·88	16·65	19·43	22·20	24·98	27·75	30·53	33·30	36·08	38·85	41·63	44·4
Copper .	2·86	5·72	8·58	11·44	14·30	17·16	20·02	22·88	25·73	28·59	31·45	34·31	37·17	40·03	42·89	45·75
Lead .	3·71	7·42	11·13	14·84	18·55	22·27	25·98	29·69	33·40	37·11	40·82	44·53	48·24	51·95	55·66	59·38
Zinc . .	2·37	4·75	7·12	9·49	11·87	14·24	16·61	18·99	21·36	23·73	26·11	28·48	30·85	33·23	35·60	37·98

Kind of Metal	Thicknesses by the Birmingham Wire Gauge															
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16
Iron . .	12·00	11·36	10·36	9·52	8·80	8·12	7·20	6·60	5·92	5·36	4·80	4·36	3·80	3·32	2·88	2·60
Steel .	12·24	11·59	10·57	9·71	8·98	8·28	7·34	6·73	6·04	5·47	4·90	4·44	3·88	3·39	2·94	2·65
Brass .	13·32	12·61	11·50	10·57	9·77	9·01	7·99	7·33	6·57	5·95	5·32	4·84	4·22	3·68	3·20	2·89
Copper .	13·73	12·99	11·85	10·89	10·07	9·29	8·24	7·55	6·77	6·13	5·49	4·99	4·35	3·80	3·29	2·97
Lead .	17·81	16·86	15·38	14·13	13·06	12·05	10·69	9·80	8·79	7·96	7·13	6·47	5·64	4·93	4·28	3·86
Zinc . .	11·39	10·78	9·84	9·04	8·36	7·71	6·84	6·27	5·62	5·09	4·56	4·14	3·61	3·15	2·73	2·47

Kind of Metal	Thicknesses by the Birmingham Wire Gauge															
	No. 17	No. 18	No. 19	No. 20	No. 21	No. 22	No. 23	No. 24	No. 25	No. 26	No. 27	No. 28	No. 29	No. 30	No. 31	No. 32
Iron . .	2·32	1·96	1·68	1·40	1·28	1·12	1·00	·88	·80	·72	·64	·56	·52	·48	·40	·36
Steel .	2·37	2·00	1·71	1·43	1·31	1·14	1·02	·90	·82	·73	·65	·57	·53	·49	·41	·37
Brass .	2·58	2·18	1·86	1·55	1·42	1·24	1·11	·98	·89	·80	·71	·62	·58	·53	·44	·40
Copper .	2·65	2·24	1·92	1·60	1·46	1·28	1·14	1·01	·92	·82	·73	·64	·59	·55	·46	·41
Lead .	3·44	2·91	2·49	2·08	1·90	1·66	1·48	1·31	1·19	1·07	·95	·83	·77	·71	·59	·53
Zinc . .	2·20	1·86	1·59	1·33	1·22	1·06	·95	·84	·76	·68	·61	·53	·49	·46	·38	·34

TABLE OF THE WEIGHT OF ROUND AND SQUARE BAR STEEL IN LBS. PER LINEAL FOOT.

Width in Ins.	Weight in Lbs. Round	Weight in Lbs. Square
1/8	·042	·053
3/16	·094	·120
1/4	·167	·213
5/16	·261	·332
3/8	·375	·478
7/16	·511	·651
1/2	·667	·850
9/16	·845	1·076
5/8	1·043	1·328
11/16	1·262	1·607
3/4	1·502	1·913
13/16	1·762	2·245
7/8	2·044	2·603
15/16	2·347	2·988
1	2·670	3·400
1/8	3·380	4·303
1/4	4·172	5·313
3/8	5·049	6·428
1/2	6·008	7·650
5/8	7·051	8·978
3/4	8·178	10·413
7/8	9·388	11·953
2	10·681	13·600
1/8	12·058	15·353
1/4	13·519	17·213
3/8	15·062	19·178
1/2	16·690	21·250
5/8	18·400	23·428
3/4	20·195	25·713
7/8	22·072	28·103
3	24·033	30·600
1/8	26·078	33·203
1/4	28·206	35·913
3/8	30·417	38·728
1/2	32·712	41·650

Width in Ins.	Weight in Lbs. Round	Weight in Lbs. Square
3 5/8	35·090	44·678
3/4	37·552	47·813
7/8	40·097	51·053
4	42·726	54·400
1/8	45·438	57·853
1/4	48·233	61·413
3/8	51·112	65·078
1/2	54·075	68·850
5/8	57·121	72·728
3/4	60·250	76·713
7/8	63·463	80·803
5	66·759	85·000
1/8	70·139	89·303
1/4	73·602	93·713
3/8	77·148	98·229
1/2	80·778	102·85
5/8	84·492	107·58
3/4	88·288	112·41
7/8	92·169	117·35
6	96·133	122·40
1/8	100·18	127·55
1/4	104·31	132·81
3/8	108·52	138·18
1/2	112·82	143·65
5/8	117·20	149·23
3/4	121·67	154·91
7/8	126·22	160·70
7	130·85	166·60
1/8	135·56	172·60
1/4	140·36	178·71
3/8	145·24	184·93
1/2	150·21	191·25
5/8	155·26	197·68
3/4	160·39	204·21

Width in Ins.	Weight in Lbs. Round	Weight in Lbs. Square
7 7/8	165·60	210·85
8	170·90	217·60
1/8	176·29	225·25
1/4	181·75	231·41
3/8	187·30	238·48
1/2	192·93	245·65
5/8	198·65	252·93
3/4	204·45	260·31
7/8	210·33	267·80
9	216·30	275·40
1/8	222·35	283·10
1/4	228·48	290·91
3/8	234·70	298·83
1/2	241·00	306·85
5/8	248·38	314·98
3/4	253·85	323·21
7/8	260·40	331·55
10	267·04	340·00
1/8	273·75	348·55
1/4	280·55	357·21
3/8	287·44	365·98
1/2	294·41	374·85
5/8	301·46	383·83
3/4	308·59	392·91
7/8	315·81	402·10
11	323·11	411·40
1/8	330·50	420·80
1/4	337·97	430·31
3/8	345·52	439·93
1/2	353·15	449·65
5/8	360·87	459·48
3/4	368·68	469·41
7/8	376·56	479·45
12	384·53	489·60

Table of the Weight of Malleable Iron Pipes in Lbs. per Lineal Foot.

Bore (ins.)	Thickness in Inches ¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	Bore (ins.)
1	3·27	5·40	7·85	10·63	—	—	—	—	—	1
¼	3·93	6·38	9·16	12·27	15·71	—	—	—	—	¼
½	4·58	7·36	10·47	13·91	17·67	21·76	—	—	—	½
¾	5·24	8·34	11·78	15·54	19·63	24·05	28·80	—	—	¾
2	5·89	9·33	13·09	17·18	21·60	26·34	31·41	36·81	—	2
¼	6·55	10·31	14·40	18·82	23·56	28·63	34·03	39·76	45·81	¼
½	7·20	11·29	15·71	20·45	25·52	30·92	36·65	42·70	49·08	½
¾	7·85	12·27	16·02	22·09	27·49	33·21	39·27	45·65	52·35	¾
3	8·51	13·25	18·32	23·72	29·45	35·50	41·88	48·59	55·63	3
¼	9·16	14·23	19·63	25·36	31·41	37·79	45·50	51·54	58·90	¼
½	9·82	15·22	20·94	27·00	33·38	40·08	47·12	54·48	62·17	½
¾	10·47	16·20	22·25	28·63	35·34	42·37	49·74	57·43	65·45	¾
4	11·13	17·18	23·56	30·27	37·30	44·67	52·35	60·38	68·72	4
¼	11·78	18·16	24·87	31·90	39·27	46·96	54·98	63·32	71·99	¼
½	12·43	19·14	26·18	33·54	41·23	49·25	57·59	66·26	75·26	½
¾	13·09	20·12	27·49	35·18	43·20	51·54	60·21	69·21	78·54	¾
5	13·74	21·11	28·80	36·82	45·16	53·83	62·83	72·16	81·8	5
¼	14·40	22·09	30·11	38·45	47·12	56·12	65·45	75·10	85·08	¼
½	15·05	23·08	31·41	40·08	49·08	58·41	68·06	78·04	88·34	½
¾	15·71	24·05	32·72	41·72	51·05	60·70	70·68	80·98	91·62	¾
6	16·36	25·03	34·03	43·36	53·01	62·99	73·29	83·93	94·89	6
¼	17·00	26·01	35·34	44·99	54·97	65·27	75·91	86·87	98·16	¼
½	17·67	27·00	36·65	46·63	56·93	67·57	78·53	89·82	101·44	½
¾	18·33	27·98	37·96	48·26	58·90	69·86	81·15	92·77	104·71	¾
7	18·98	28·96	39·26	49·90	60·86	72·15	83·77	95·71	107·98	7
¼	19·63	29·93	40·57	51·53	62·82	74·44	86·38	98·65	111·25	¼
½	20·28	30·92	41·88	53·17	64·79	76·73	89·00	101·60	114·52	½
¾	20·94	31·90	43·19	54·81	66·75	79·02	91·62	104·24	117·80	¾
8	21·60	32·89	44·51	56·45	68·72	81·32	94·24	107·50	121·07	8
¼	22·25	33·87	45·81	58·08	70·68	83·60	96·86	110·43	124·34	¼
½	22·91	34·85	47·12	59·72	72·64	85·90	99·47	113·38	127·62	½
¾	23·56	35·83	48·43	61·35	74·61	88·18	102·29	116·33	130·89	¾
9	24·21	36·81	49·73	62·99	76·56	90·47	104·71	119·27	134·16	9
¼	24·87	37·79	51·05	64·62	78·53	92·77	107·33	122·22	137·43	¼
½	25·52	38·78	52·35	66·26	80·50	95·06	109·95	125·16	140·70	½
¾	26·18	39·75	53·66	67·90	82·46	97·35	112·56	128·10	143·97	¾
10	26·83	40·74	54·98	69·54	84·43	99·64	115·18	130·05	147·25	10
¼	27·48	41·72	56·28	71·17	86·38	101·92	117·79	133·99	150·52	¼
½	28·15	42·71	57·60	72·81	88·35	104·22	120·42	136·95	153·80	½
¾	28·80	43·69	58·90	74·44	90·31	106·51	123·04	139·89	157·07	¾
11	29·45	44·66	60·20	76·07	92·27	108·80	125·65	142·83	160·33	11
½	30·75	46·62	62·82	79·35	96·20	113·38	130·88	147·95	166·88	½
12	32·07	48·60	65·45	82·63	100·13	117·15	136·13	154·61	173·43	12
Bore (ins.)	¼	⅜	½	⅝	¾	⅞	1	1⅛	1¼	Bore (ins.)
	Thickness in Inches									

Table of the Weight of Cast-iron Pipes in Lbs. per Lineal Foot.

Bore (ins.)	Thickness in Inches									Bore (ins.)
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	
1	3·06	5·06	7·36	9·97	—	—	—	—	—	1
$\frac{1}{4}$	3·69	5·98	8·59	11·51	14·73	—	—	—	—	$\frac{1}{4}$
$\frac{1}{2}$	4·29	6·90	9·82	13·04	16·56	20·4	—	—	—	$\frac{1}{2}$
$\frac{3}{4}$	4·91	7·83	11·05	14·57	18·41	22·55	27·00	—	—	$\frac{3}{4}$
2	5·53	8·75	12·27	16·11	20·25	24·7	29·45	34·46	—	2
$\frac{1}{4}$	6·14	9·66	13·50	17·64	22·09	26·84	31·85	37·28	42·95	$\frac{1}{4}$
$\frac{1}{2}$	6·74	10·58	14·72	19·17	23·92	28·93	34·36	40·03	46·02	$\frac{1}{2}$
$\frac{3}{4}$	7·36	11·50	15·95	20·70	25·71	31·14	36·81	42·80	49·08	$\frac{3}{4}$
3	7·98	12·43	17·18	22·19	27·62	33·29	39·28	45·56	52·16	3
$\frac{1}{4}$	8·59	13·34	18·35	23·78	29·45	35·44	41·72	48·32	55·22	$\frac{1}{4}$
$\frac{1}{2}$	9·20	14·21	19·64	25·31	31·30	37·58	44·18	51·08	58·29	$\frac{1}{2}$
$\frac{3}{4}$	9·76	15·19	20·86	26·85	33·13	39·73	46·63	53·84	61·36	$\frac{3}{4}$
4	10·44	16·11	22·10	28·38	34·98	41·88	49·09	56·61	64·43	4
$\frac{1}{4}$	11·10	17·03	23·37	29·97	36·87	44·03	51·60	59·42	67·55	$\frac{1}{4}$
$\frac{1}{2}$	11·66	17·94	24·54	31·44	38·65	46·17	53·99	62·12	70·56	$\frac{1}{2}$
$\frac{3}{4}$	12·27	18·87	25·77	32·98	40·50	48·32	56·45	64·89	73·63	$\frac{3}{4}$
5	12·88	19·78	26·99	34·51	42·33	50·46	58·90	67·64	76·69	5
$\frac{1}{4}$	13·50	20·71	28·23	36·05	44·18	52·62	61·36	70·41	79·77	$\frac{1}{4}$
$\frac{1}{2}$	14·11	21·63	29·45	37·58	46·02	54·76	63·81	73·17	82·84	$\frac{1}{2}$
$\frac{3}{4}$	14·73	22·55	30·68	39·12	47·86	56·91	66·27	75·94	85·91	$\frac{3}{4}$
6	15·34	23·47	31·91	40·65	49·70	59·06	68·73	78·70	88·75	6
$\frac{1}{4}$	15·95	24·39	33·13	42·18	51·54	61·21	71·18	81·23	92·04	$\frac{1}{4}$
$\frac{1}{2}$	16·57	25·31	34·36	43·72	53·39	63·36	73·41	84·22	95·10	$\frac{1}{2}$
$\frac{3}{4}$	17·18	26·23	35·59	45·26	55·23	65·28	76·09	86·97	98·18	$\frac{3}{4}$
7	17·79	27·15	36·82	46·79	56·84	67·65	78·53	89·74	101·2	7
$\frac{1}{4}$	18·41	28·08	38·05	48·10	58·91	69·79	81·00	92·50	104·3	$\frac{1}{4}$
$\frac{1}{2}$	19·03	29·00	39·05	49·86	60·74	71·95	83·45	95·26	107·4	$\frac{1}{2}$
$\frac{3}{4}$	19·64	29·93	40·50	51·38	62·59	74·09	85·90	98·02	110·5	$\frac{3}{4}$
8	20·02	30·83	41·71	52·92	64·42	76·23	88·35	100·8	113·5	8
$\frac{1}{4}$	20·86	31·74	42·95	54·45	66·26	78·38	90·81	103·5	116·6	$\frac{1}{4}$
$\frac{1}{2}$	21·69	32·90	44·40	56·21	68·33	80·76	93·49	106·5	119·9	$\frac{1}{2}$
$\frac{3}{4}$	22·09	33·59	45·40	57·52	69·95	82·68	95·72	109·1	122·7	$\frac{3}{4}$
9	22·71	34·52	46·64	59·07	71·80	84·84	98·18	111·8	125·8	9
$\frac{1}{4}$	23·31	35·43	47·86	60·59	73·63	86·97	100·6	114·6	128·9	$\frac{1}{4}$
$\frac{1}{2}$	23·93	36·36	49·09	62·13	75·47	89·13	103·1	117·4	131·9	$\frac{1}{2}$
$\frac{3}{4}$	24·55	37·28	50·32	63·66	77·32	91·28	105·5	120·1	135·0	$\frac{3}{4}$
10	25·16	38·20	51·54	65·20	79·16	93·42	108·0	122·9	138·1	10
$\frac{1}{4}$	25·77	39·11	52·77	66·73	80·99	95·57	110·4	125·6	141·1	$\frac{1}{4}$
$\frac{1}{2}$	26·38	40·04	54·00	68·26	82·84	97·71	112·9	128·4	144·2	$\frac{1}{2}$
$\frac{3}{4}$	27·00	40·96	55·22	69·80	84·67	99·86	1[illegible]5·4	131·2	147·3	$\frac{3}{4}$
11	27·62	41·88	56·46	71·33	86·52	102·0	117·8	133·9	150·3	11
$\frac{1}{2}$	28·84	43·71	58·90	74·39	90·19	106·3	122·7	139·4	156·4	$\frac{1}{2}$
12	30·06	45·55	61·35	77·46	93·60	110·6	127·6	145·0	162·6	12
Bore (ins.)	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	Bore (ins.)
	Thickness in Inches									

Table of the Weight of Lead Pipe in Lbs. per Lineal Foot, and Lengths in which it is usually Manufactured.

Lgth. (ft.)	Bore (ins.)	Weight per Foot in Lbs.							Lgth. (ft.)	Bore (ins.)	Wght. per Ft. in Lbs.			
15 *	½	·933	1·07	1·2	1·47	1·73	1·87	2·33	12	3	9·0	—	—	—
15 *	⅝	1·2	1·47	1·67	1·80	—	—	—	10	2¼	13·0	—	—	—
15 *	¾	1·47	1·60	1·73	1·87	2·13	2·4	3·00	10	2½	9·6	10·5	12·0	—
15 *	1	1·87	2·4	2·8	3·00	3·60	3·93	4·20	10	3	11·6	12·0	13·4	15·0
12 †	1¼	3·00	3·17	3·50	4·33	5·08	5·25	—	10	3½	13·5	15·0	16·6	18·4
12 †	1½	3·50	4·00	4·67	5·08	6·00	7·00	—	10	4	13·5	16·0	18·4	20·0
12 †	1¾	5·83	7·00	7·33	8·00	—	—	—	10	4½	20·0	21·6	23·4	—
12 †	2	7·00	8·00	9·33	—	—	—	—	10	5	23·4	25·4	28·0	—
12 †	2½	10·5	—	—	—	—	—	—	10	6	33·0	—	—	—

* Also in 60-feet coils. † Also in 36-feet coils.

Table of the Weight of Round Copper Rod in lbs. per Lineal Foot.

Diam. (ins.)	Weight	Diam. (ins.)	Weight	Diam. (ins.)	Weight	Diam. (ins.)	Weight	Diam. (ins.)	Weight
¼	·1892	¾	1·7027	1¼	4·7298	2⅛	13·6677	3⅛	29·5594
5/16	·2956	13/16	1·9982	1 5/16	5·2140	2¼	15·3251	3¼	31·9722
⅜	·4256	⅞	2·3176	1⅜	5·7228	2⅜	17·0750	3⅜	34·4815
7/16	·5794	15/16	2·6605	1½	6·8109	2½	18·9161	3½	37·0808
½	·7567	1	3·0270	1⅝	7·9931	2⅝	20·8562	3⅝	39·7774
9/16	·9578	1 1/16	3·4170	1¾	9·2702	2¾	22·8913	3¾	42·5680
⅝	1·1824	1⅛	3·8312	1⅞	10·6420	2⅞	25·0188	3⅞	45·4550
11/16	1·4307	1 3/16	4·2688	2	12·1082	3	27·2435	4	48·4330

Table of the Weight of Cast-iron Balls.

Diam. (ins.)	Wght. (lbs.)	Diam. (ins.)	Wght. (lbs.)	Diam. (ins.)	Weight (lbs.)	Diam. (ins.)	Weight (lbs.)	Diam. (ins.)	Weight (lbs.)
—	—	—	—	4½	12·55	6⅜	35·68	8½	84·57
1	·14	2¾	2·86	4⅝	13·62	6½	37·81	8¾	92·25
1⅛	·20	2⅞	3·27	4¾	14·76	6⅝	40·04	9	100·39
1¼	·27	3	3·72	4⅞	15·95	6¾	42·35	9¼	108·99
1⅜	·36	3⅛	4·20	5	17·21	6⅞	44·75	9½	118·06
1½	·47	3¼	4·73	5⅛	18·54	7	47·23	9¾	127·63
1⅝	·59	3⅜	5·29	5¼	19·93	7⅛	49·80	10	137·70
1¾	·74	3½	5·90	5⅜	21·38	7¼	52·47	10¼	148·29
1⅞	·91	3⅝	6·56	5½	22·91	7⅜	55·23	10½	159·40
2	1·10	3¾	7·26	5⅝	24·51	7½	58·09	10¾	171·06
2⅛	1·32	3⅞	8·01	5¾	26·18	7⅝	60·04	11	183·28
2¼	1·57	4	8·81	5⅞	27·92	7¾	64·09	11¼	196·06
2⅜	1·84	4⅛	9·67	6	29·74	7⅞	67·24	11½	209·42
2½	2·15	4¼	10·57	6⅛	31·64	8	70·50	11¾	223·38
2⅝	2·49	4⅜	11·53	6¼	33·62	8¼	77·32	12	237·94

Shrinkage of Castings.

The usual allowance for each foot in length is as follows:—

In large cylinders . $=\frac{3}{32}$ inch.
In small „ . $=\frac{1}{16}$ „
In beams and girders $=\frac{1}{10}$ „
In thick brass . $=\frac{5}{32}$ „
In thin „ . $=\frac{4}{32}$ „
In zinc . . $=\frac{5}{16}$ inch.
In lead . . $=\frac{5}{16}$ „
In tin . . $=\frac{1}{4}$ „
In copper . . $=\frac{3}{16}$ „
In bismuth . $=\frac{5}{32}$ „

In cast-iron pipes $=\frac{1}{8}$ inch.

Table of the Weight of Copper Pipe in Lbs. per Lineal Foot.

Thickness (ins.)	Bore of Pipe in Inches								Thickness (ins.)
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	
$\frac{1}{32}$	·11	·13	·15	·20	·25	·30	·34	·39	$\frac{1}{32}$
$\frac{1}{16}$	·24	·28	·33	·43	·52	·61	·71	·80	$\frac{1}{16}$
$\frac{3}{32}$	·39	·46	·53	·67	·82	·96	1·10	1·24	$\frac{3}{32}$
$\frac{1}{8}$	·57	·66	·76	·95	1·14	1·32	1·51	1·70	$\frac{1}{8}$
$\frac{5}{32}$	·77	·89	1·01	1·24	1·48	1·71	1·95	2·19	$\frac{5}{32}$
$\frac{3}{16}$	·99	1·14	1·28	1·56	1·84	2·13	2·41	2·70	$\frac{3}{16}$
$\frac{7}{32}$	1·24	1·41	1·57	1·90	2·23	2·57	2·90	3·23	$\frac{7}{32}$
$\frac{1}{4}$	1·51	1·70	1·89	2·27	2·65	3·03	3·41	3·78	$\frac{1}{4}$
Thickness (ins.)	Bore of Pipe in Inches								Thickness (ins.)
	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	
$\frac{1}{16}$	·90	·99	1·09	1·18	1·28	1·37	1·47	1·56	$\frac{1}{16}$
$\frac{1}{8}$	1·89	2·08	2·27	2·46	2·65	2·84	3·03	3·22	$\frac{1}{8}$
$\frac{3}{16}$	2·98	3·26	3·55	3·83	4·12	4·40	4·68	4·97	$\frac{3}{16}$
$\frac{1}{4}$	4·16	4·54	4·91	5·30	5·67	6·05	6·43	6·81	$\frac{1}{4}$
Thickness (ins.)	Bore of Pipe in Inches								Thickness (ins.)
	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	
$\frac{1}{16}$	1·66	1·75	1·84	1·94	2·04	2·13	2·22	2·32	$\frac{1}{16}$
$\frac{1}{8}$	3·41	3·59	3·78	3·98	4·16	4·35	4·54	4·73	$\frac{1}{8}$
$\frac{3}{16}$	5·25	5·53	5·82	6·10	6·39	6·67	6·95	7·24	$\frac{3}{16}$
$\frac{1}{4}$	7·19	7·57	7·94	8·33	8·70	9·08	9·46	9·84	$\frac{1}{4}$
Thickness (ins.)	Bore of Pipe in Inches								Thickness (ins.)
	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	4	
$\frac{1}{16}$	2·41	2·51	2·60	2·70	2·79	2·89	2·98	3·08	$\frac{1}{16}$
$\frac{1}{8}$	4·92	5·11	5·30	5·49	5·68	5·87	6·05	6·25	$\frac{1}{8}$
$\frac{3}{16}$	7·52	7·81	8·09	8·37	8·66	8·94	9·22	9·51	$\frac{3}{16}$
$\frac{1}{4}$	10·22	10·60	10·97	11·35	11·73	12·11	12·49	12·51	$\frac{1}{4}$

Table of the Weight of Hoop Iron in Lbs. per Lineal Foot.

Breadth (ins.) .	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$
Thickness (B.W.G.)	23	22	21	20	19	18	17
Weight (lbs.) . .	·0313	·0466	·0666	·0875	·1225	·1633	·2175
Breadth (ins.) .	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
Thickness (B.W.G.)	16	15	15	14	13	13	12
Weight (lbs.) . .	·2708	·3300	·3600	·4842	·6333	·7125	·9083

Table of the Weight of Iron, Steel, Brass, and Copper Wire in Lbs. per Lineal Foot.

B.W.G.	Lbs. per Lineal Foot				B.W.G.	Lbs. per Lineal Foot			
	Iron	Steel	Brass	Copper		Iron	Steel	Brass	Copper
0	·3058	·3092	·3343	·3517	11	·0413	·0418	·0452	·0475
1	·2575	·2604	·2815	·2962	12	·0314	·0318	·0343	·0361
2	·2134	·2157	·2332	·2454	13	·0234	·0236	·0255	·0269
3	·1802	·1822	·1970	·2072	14	·0169	·0171	·0185	·0195
4	·1511	·1528	·1652	·1738	15	·0137	·0139	·0150	·0158
5	·1246	·1259	·1362	·1433	16	·0105	·0106	·0115	·0121
6	·1145	·1157	·1251	·1316	17	·0080	·0081	·0087	·0092
7	·0925	·0935	·1011	·1064	18	·0061	·0062	·0067	·0070
8	·0729	·0737	·0797	·0838	19	·0047	·0047	·0051	·0054
9	·0660	·0668	·0722	·0759	20	·0032	·0033	·0034	·0037
10	·0496	·0502	·0543	·0571.	21	·0017	·0018	·0019	·0022

Table of the Weight of Nuts and Bolt-heads in Lbs. per Pair.

Diameter of bolt (ins.) .	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Hexagon head and nut .	·050	·100	·200	·365	·500	·770	1·25
Square head and nut .	·062	·121	·240	·400	·560	·880	1·31
Diameter of bolt (ins.) .	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$
Hexagon head and nut .	1·75	2·13	3·00	3·75	5·75	8·75	17·00
Square head and nut .	2·10	2·56	3·60	4·42	7·00	10·5	21·00

Limiting Sizes of Plates (Admiralty).

Mild Steel.

Thickness.	10 lb.	12 lb.	14 lb.	17 lb.	20 lb.	22½ lb.	25 lb.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Length . .	33 0	33 0	36 0	40 0	50 0	50 0	45 0
Width . .	6 10	7 0	7 3	8 0	8 3	8 3	8 3
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Area . .	145	155	170	200	240	240	240

Thickness.	27½ lb.	30 lb.	35 lb.	40 and 45 lb.	50 and 55 lb.	60 lb.	70 and 80 lb.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Length . .	45 0	45 0	45 0	45 0	40 0	40 0	30 0
Width . .	8 3	8 3	8 3	8 3	8 0	8 0	7 6
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Area . .	240	240	210	210	200	200	150

High Tensile (H.T.) Steel.

Thickness.	10 lb.	12 lb.	14 lb.	17 lb.	20 lb.	22½ lb.	27½ lb.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Length . .	40 0	40 0	40 0	40 0	50 0	50 0	50 0
Width . .	6 0	6 6	7 3	8 3	9 6	9 6	10 0
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Area . .	150	170	190	220	280	280	280

Thickness.	30 lb.	35 lb.	40 and 45 lb.	50 and 55 lb.	60 lb.	70 and 80 lb.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Length . .	50 0	50 0	50 0	50 0	50 0	40 0
Width . .	10 0	10 6	10 6	11 0	11 0	9 0
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Area . .	280	300	300	350	350	280

Comparison of Numbers of the Principal Plate Gauges.

Whitworth's Decimal Gauge, 1000ths of an Inch	Corresponding Numbers of the Old			Whitworth's Decimal Gauge, 1000ths of an Inch	Corresponding Numbers of the Old		
	Birmingham Wire Gauge	Birmingham Plate Gauge	Lancashire Gauge		Birmingham Wire Gauge	Birmingham Plate Gauge	Lancashire Gauge
1	—	—	—	50	18	16	55
2	—	—	—	55	—	17*	54
3	—	—	—	60	17*	18	52
4	36	1	—	65	16	19	51
5	35	2	—	70	15*	21*	49
6	—	—	—	75	—	22	47
7	34	—	—	80	—	24*	45
8	33	3	—	85	14*	—	43
9	32	—	—	90	—	—	42
10	31	4	—	95	13	25	41
11	—	—	—	100	—	26**	38
12	30	5	—	110	12	27**	34
13	29	6	80	120	11	28	31*
14	28	—	79	135	10	31*	29
15	—	7	78	150	9*	34*	23
16	27	8	77	165	8	36*	19
17	—	—	—	180	7	—	13
18	26	—	76	200	6**	—	5**
19	—	9	—	220	5	—	2
20	25	—	75	240	4*	—	C*
22	24	—	74	260	3	—	G
24	23*	10	72	280	2**	—	K
26	—	—	71	300	1	—	N*
28	22	11	70	325	—	—	P*
30	—	—	68	350	—	—	S*
32	21	—	66	375	00**	—	V*
34	—	12	64	400	—	—	X**
36	20	13	62	425	000	—	—
38	—	—	61	450	0000**	—	—
40	19*	14	59	475			
45	—	15*	56	500			

Note.—Sizes which differ from those in the first column by more than ·002 of an inch are marked thus **; those of which the difference exceeds ·001, thus *. All others either correspond exactly, or are within ·001 of an inch.

Legal Standard Wire Gauge.

Descriptive Number	Equivalents in Parts of an Inch	Metric Equivalent in Millimetres	Descriptive Number	Equivalents in Parts of an Inch	Metric Equivalent in Millimetres
No. 7/0	0·500	12·700	No. 23	0·024	0·610
6/0	·464	11·785	24	·022	·559
5/0	·432	10·973	25	·020	·508
4/0	·400	10·160	26	·018	·457
3/0	·372	9·449	27	·0164	·4166
2/0	·348	8·839	28	·0148	·3759
0	·324	8·229	29	·0136	·3454
1	·300	7·620	30	·0124	·3150
2	·276	7·010	31	·0116	·2946
3	·252	6·401	32	·0108	·2743
4	·232	5·893	33	·0100	·2540
5	·212	5·385	34	·0092	·2337
6	·192	4·877	35	·0084	·2134
7	·176	4·470	36	·0076	·1930
8	·160	4·064	37	·0068	·1727
9	·144	3·658	38	·0060	·1524
10	·128	3·251	39	·0052	·1321
11	·116	2·946	40	·0048	·1219
12	·104	2·642	41	·0044	·1118
13	·092	2·337	42	·0040	·1016
14	·080	2·032	43	·0036	·0914
15	·072	1·829	44	·0032	·0813
16	·064	1·626	45	·0028	·0711
17	·056	1·422	46	·0024	·0610
18	·048	1·219	47	·0020	·0508
19	·040	1·016	48	·0016	·0406
20	·036	0·914	49	·0012	·0305
21	·032	·813	50	·0010	·0254
22	·028	·711			

TABLE OF WEIGHT AND STRENGTH OF STEEL WIRE.

Standard Wire Gauge	Diameter		Sectional Area	Weight of		Approximate Length of 1 Cwt.	Breaking Strain if tempered to 100 Tons per Square Inch	Standard Wire Gauge
				100 Yards	1 Mile			
	Inch	Mm.	Square Inch	Lbs.	Lbs.	Yards	Lbs.	
7/0	·500	12·7	·1963	193·4	3,404	58	43,975	7/0
6/0	·464	11·8	·1691	166·5	2,930	67	37,854	6/0
5/0	·432	11·0	·1466	144·4	2,541	78	32,823	5/0
4/0	·400	10·2	·1257	123·8	2,179	91	28,144	4/0
3/0	·372	9·4	·1087	107·1	1,885	105	24,354	3/0
2/0	·348	8·8	·0951	93·7	1,649	120	21,302	2/0
0	·324	8·2	·0824	81·2	1,429	138	18,464	0
1	·300	7·6	·0707	69·6	1,225	161	15,831	1
2	·276	7·0	·0598	58·9	1,037	190	13,398	2
3	·252	6·4	·0499	49·1	864	228	11,169	3
4	·232	5·9	·0423	41·6	732	269	9,467	4
5	·212	5·4	·0353	34·8	612	322	7,904	5
6	·192	4·9	·0290	28·5	502	393	6,486	6
7	·176	4·5	·0243	24·0	422	467	5,450	7
8	·160	4·1	·0201	19·8	348	566	4,503	8
9	·144	3·7	·0163	16·0	282	700	3,648	9
10	·128	3·3	·0129	12·7	223	882	2,882	10
11	·116	3·0	·0106	10·4	183	1,077	2,368	11
12	·104	2·6	·0085	8·4	148	1,333	1,903	12
13	·092	2·3	·0066	6·5	114	1,723	1,489	13
14	·080	2·0	·0050	5·0	88	2,240	1,126	14
15	·072	1·8	·0041	4·0	70	2,800	912	15
16	·064	1·6	·0032	3·2	56	3,500	721	16
17	·056	1·4	·0025	2·4	42	4,667	552	17
18	·048	1·2	·0018	1·8	32	6,222	406	18
19	·040	1·0	·0013	1·2	21	9,333	281	19
20	·036	·9	·0010	1·0	18	11,200	228	20

DIMENSIONS AND PROPERTIES OF BRITISH STANDARD SECTIONS.

Explanation of Tables.

The particulars in the following tables are taken by permission from publication No. 6 of the Engineering Standards Committee.* They are in many cases amplified and arranged in the form given in the *Pocket Companion* of Messrs. Dorman, Long & Co., Ltd., and reproduced here by permission.

Thicknesses, within limits, other than those given can generally be rolled; but in angle bulbs and Z bars the increase of flange must be about one-half that of the web thickness; while in bulb tees and channels the web thickness alone can be varied.

For intermediate thicknesses the radius of gyration is approximately constant in angles, angle bulbs, tees, and Z bars, so that the moment of inertia varies directly as the sectional area; but in bulb tees and channels the effect of varying the web thickness is best allowed for by directly calculating the moment of inertia of the web.

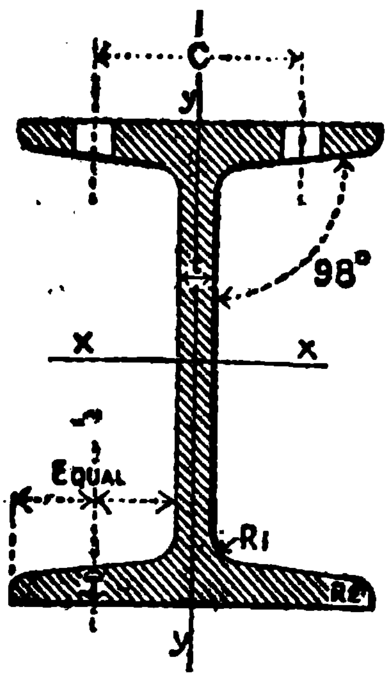
The least radius of gyration ($=\sqrt{}$least moment of inertia $\div$ sectional area) has been determined for all sections. In sections such as I beams, channels, tees, tee bulbs, and equal angles, the corresponding axis is either the axis of symmetry or the one at right angles to it. In the case of unequal angles, bulb angles, and Z bars, the position of the axis about which the radius is least is given and marked 'minor axis'. The maximum moment of inertia is always about an axis perpendicular to that for the minimum, these forming the 'principal axes' (p. 73); its value in unsymmetrical sections is found by subtracting the minimum m.i. from the sum of the m.i. about XX and YY. From the maximum and minimum m.i. that about any other axis is found by the rule on p. 73.

The section modulus about XX is equal to the moment of inertia about XX divided by the greatest distance of any part of the section from XX; symbolically it $= I/y =$ bending moment for unit stress.

* Report No. 6. Properties of British Standard Sections, published by Messrs. Crosby Lockwood & Son, price 2s. 6d.

Dimensions and Properties of British Standard I Beams in Inch Units.

Fig. 152.



Reference Mark. BSB.	Size. Inches.	Weight per Foot-lbs.	Diagram. Web t	Flange T.	Radius. R 1.	R 2.
30	24 × 7½	100	·6	1·07	·7	·35
29	20 × 7½	89	·6	1·01	·7	·35
28	18 × 7	75	·55	·928	·65	·32
27	16 × 6	62	·55	·847	·65	·32
26	15 × 6	59	·5	·88	·6	·3
25	15 × 5	42	·42	·647	·52	·26
24	14 × 6	57	·5	·873	·6	·3
23	14 × 6	46	·4	·698	·5	·25
22	12 × 6	54	·5	·888	·6	·3
21	12 × 6	44	·4	·717	·5	·25
20	12 × 5	32	·35	·55	·45	·22
19	10 × 8	70	·6	·97	·7	·35
18	10 × 6	42	·4	·736	·5	·25
17	10 × 5	30	·36	·552	·46	·2[illegible]
16	9 × 7	58	·55	·924	·65	·3[illegible]
15	9 × 4	21	·3	·46	·4	·2
14	8 × 6	35	·44	·597	·54	·27
13	8 × 5	28	·35	·575	·45	·22
12	8 × 4	18	·28	·402	·38	·19
11	7 × 4	16	·25	·387	·35	·17
10	6 × 5	25	·41	·52	·51	·25
9	6 × 4½	20	·37	·431	·47	·23
8	6 × 3	12	·26	·348	·36	·18
7	5 × 4½	18	·29	·448	·39	·19
6	5 × 3	11	·22	·376	·32	·16
5	4¾ × 1¾	6·5	·18	·325	·28	·14
4	4 × 3	9·5	·22	·336	·32	·16
3	4 × 1¾	5	·17	·24	·27	·13
2	3 × 3	8·5	·2	·332	·3	·15
1	3 × 1½	4	·16	·248	·26	·13

The properties of British Standard Sections in above table are published by permission of the Engineering Standards Committee.

Dimensions and Properties of British Standard I Beams in Inch Units.

Area. Square Inches.	Moments of Inertia.		Radii of Gyration. Inches.		Section Modulus.	Centres of Holes C Inches.	Reference Mark.
	About X–X.	About Y–Y.	About X–X.	About Y–Y.	About X–X.		BSB.
29·4	2654	66·92	9·5	1·5	221·1	4·5	30
26·17	1670	62·63	7·99	1·54	167·0	4·5	29
22·06	1149	47·04	7·21	1·46	127·6	4·0	28
18·23	725·7	27·08	6·31	1·21	90·71	3·5	27
17·35	628·9	28·22	6·02	1·27	83·85	3·5	26
12·35	428	11·81	5·88	·978	57·06	2·75	25
16·76	532·9	27·96	5·63	1·29	76·12	3·5	24
13·53	440·5	21·6	5·7	1·26	62·92	3·5	23
15·88	375·5	28·3	4·83	1·33	62·58	3·5	22
12·94	315·8	22·27	4·93	1·31	52·55	3·5	21
9·41	220	9·753	4·83	1·01	36·66	2·75	20
20·6	344·9	71·67	4·09	1·86	68·98	4·75	19
12·35	211·5	22·95	4·13	1·36	42·3	3·5	18
8·82	145·6	9·79	4·06	1·05	29·12	2·75	17
17·06	229·5	46·3	3·66	1·64	51·0	4·0	16
6·176	81·1	4·2	3·62	·824	18·02	2·25	15
10·29	110·5	17·95	3·27	1·32	27·62	3·5	14
8·24	89·32	10·26	3·29	1·11	22·33	2·75	13
5·294	55·69	3·578	3·24	·822	13·92	2·25	12
4·706	39·21	3·414	2·88	·851	11·2	2·25	11
7·35	43·61	9·116	2·43	1·11	14·53	2·75	10
5·88	34·62	5·415	2·42	·959	11·54	2·5	9
3·53	20·21	1·339	2·39	·616	6·736	1·5	8
5·29	22·69	5·664	2·07	1·03	9·076	2·5	7
3·235	13·61	1·462	2·05	·672	5·444	1·5	6
1·912	6·77	·263	1·87	·37	2·833	—	5
2·794	7·52	1·281	1·64	·677	3·76	1·5	4
1·47	3·668	·186	1·58	·355	1·834	—	3
2·5	3·787	1·262	1·23	·71	2·524	1·5	2
1·176	1·659	·124	1·18	·324	1·106	—	1

The dimension C, giving the position of the holes, is in accordance with the practice of Messrs. Dorman, Long & Co., Ltd., from whose *Pocket Companion* this table has been taken. The areas and properties apply to the full section without holes.

British Standard Channels.
Dimensions and Properties in Inch Units.

Fig. 168.

Y

y

Y

Reference Mark. B.S.C.	Size	Standard Thicknesses. t	Standard Thicknesses. T	Radii. R	Radii. r	Weight per Foot lbs.
27	15 × 4	525	630	[illegible]	440	41 94
26	12 × 4	·525	625	625	425	36 47
25	12 × 3½	·500	·600	600	425	32 88
24	12 × 3½	375	·500	[illegible]	·350	26·10
23	11 × 4	500	·600	600	425	33·22
22	11 × 3½	475	575	·575	400	29 82
21	10 × 4	475	575	575	400	30·16
20	10 × 3½	475	575	575	400	28 21
19	10 × 3½	375	·500	500	350	23 55
18	9 × 4	·475	·575	575	·400	28 55
17	9 × 3½	·450	550	550	·375	25·39
16	9 × 3½	375	·500	500	[illegible]	22 27
15	9 × 3	375	·437	·437	·350	19 37
14	8 × 4	[illegible]	550	550	·375	25 73
13	8 × 3½	·425	·525	525	·375	22 72
12	8 × 3	375	500	500	350	19 30
11	8 × 2½	312	·437	437	[illegible]	15 12
10	7 × 3½	400	500	500	·350	20 23
9	7 × 3	375	475	475	325	17 56
8	6 × 3½	375	·475	475	325	17·90
7	6 × 3	[illegible]	475	·475	325	16 29
6	6 × 3	312	·437	·437	·300	14 49
5	6 × 2½	312	·375	·375	620	12 04
[illegible]	5 × 2½	312	·375	375	260	10 98
3	4 × 2	250	·375	375	·260	7 96
2	3½ × 2	250	·312	312	·220	6 75
1	3 × 1½	[illegible]	312	[illegible]	[illegible]	5 27

The properties of British Standard Sections in above table are published by permission of the Engineering Standards Committee.

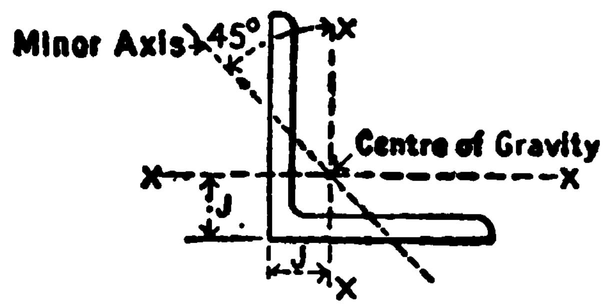
BRITISH STANDARD CHANNELS.

DIMENSIONS AND PROPERTIES IN INCH UNITS.

Area. Square Inches.	P Dimension.	Moments of Inertia.		Section Moduli.		Radii of Gyration. Inches.		Reference Mark
		About XX.	About YY.	About XX.	About YY.	About XX.	About YY.	BSC.
12·334	·935	377·0	14·55	50·27	4·748	5·53	1·09	27
10·727	1·031	218·2	13·65	36·36	4·599	4·51	1·13	26
9·671	·867	190·7	8·922	31·79	3·389	4·44	·960	25
7·675	·860	158·6	7·572	26·44	2·868	4·55	·993	24
9·771	1·063	170·5	12·812	30·99	4·362	4·18	1·145	23
8·771	·896	148·6	8·421	27·02	3·234	4·12	·980	22
8·871	1·102	130·7	12·02	26·14	4·147	3·84	1·16	21
8·296	·933	117·9	8·194	23·59	3·192	3·77	·994	20
6·925	·933	102·6	7·187	20·52	2·800	3·85	1·02	19
8·396	1·151	101·7	11·635	22·59	4·084	3·48	1·177	18
7·469	·971	88·07	7·660	19·57	3·029	3·43	1·01	17
6·550	·976	79·90	6·963	17·76	2·759	3·49	1·03	16
5·696	·754	65·18	4·021	14·48	1·790	3·38	·840	15
7·569	1·201	74·02	10·790	18·50	3·855	3·13	1·194	14
6·682	1·011	63·76	7·067	15·94	2·839	3·09	1·03	13
5·675	·844	53·43	4·329	13·36	2·008	3·07	·873	12
4·448	·666	41·09	2·283	10·27	1·245	3·04	·716	11
5·950	1·061	44·55	6·498	12·73	2·664	2·74	1·04	10
5·166	·874	37·63	4·017	10·75	1·889	2·70	·882	9
5·266	1·119	29·66	5·907	9·885	2·481	2·36	1·06	8
4·791	·928	26·03	3·822	8·678	1·845	2·33	·893	7
4·261	·938	24·01	3·503	8·003	1·699	2·37	·907	6
3·542	·704	18·76	1·880	6·254	1·047	2·302	·729	5
3·230	·757	12·13	1·774	4·854	1·018	1·94	·741	4
2·341	·656	5·709	·843	2·855	·627	1·56	·600	3
1·986	·645	3·701	·713	2·115	·526	1·37	·599	2
1·549	·484	1·994	·296	1·329	·291	1·135	·437	1

British Standard Equal Angles.
Dimensions and Properties in Inch Units.

Fig. 154.



Reference Mark. BSEA.	Size and Thickness.	Area. Square Inches.	Weight per Foot-lbs.	Radii. Root.	Radii. Toe.	Dimension. J	Moment of Inertia. XX	Section Modulus. XX	Least Radius of Gyration.
16	8 × 8 × $\frac{1}{2}$	7·75	26·35	·600	·425	2·15	47·4	8·10	1·58
16	,, ,, $\frac{5}{8}$	9·609	32·67	·600	·425	2·20	58·2	10·03	1·57
16	,, ,, $\frac{3}{4}$	11·437	38·89	·600	·425	2·25	68·5	11·91	1·56
16	,, ,, $\frac{7}{8}$	13·234	45·00	·600	·425	2·30	78·41	13·76	1·56
14	6 × 6 × $\frac{3}{8}$	4·362	14·83	·475	·325	1·61	14·99	3·41	1·19
14	,, ,, $\frac{1}{2}$	5·753	19·56	·475	·325	1·66	19·52	4·50	1·18
14	,, ,, $\frac{5}{8}$	7·112	24·18	·475	·325	1·71	23·8	5·55	1·18
14	,, ,, $\frac{3}{4}$	8·441	28·70	·475	·325	1·76	27·8	6·56	1·17
14	,, ,, 1	11·003	37·41	·475	·325	1·85	35·09	8·46	1·16
13	5 × 5 × $\frac{5}{16}$	3·028	10·30	·425	·300	1·34	7·18	1·96	·99
13	,, ,, $\frac{3}{8}$	3·610	12·27	·425	·300	1·37	8·51	2·34	·98
13	,, ,, $\frac{1}{2}$	4·750	16·15	·425	·300	1·42	11·0	3·07	·98
13	,, ,, $\frac{5}{8}$	5·860	19·92	·425	·300	1·47	13·4	3·80	·93
13	,, ,, $\frac{3}{4}$	6·938	23·59	·425	·300	1·51	15·5	4·44	·96
12	4½ × 4½ × $\frac{3}{8}$	3·236	11·00	·400	·275	1·22	6·14	1·87	·88
12	,, ,, $\frac{1}{2}$	4·252	14·46	·400	·275	1·29	7·92	2·47	·87
12	,, ,, $\frac{5}{8}$	5·236	17·80	·400	·275	1·34	9·56	3·03	·87
12	,, ,, $\frac{3}{4}$	6·189	21·04	·400	·275	1·39	11·1	3·57	·87
11	4 × 4 × $\frac{5}{16}$	2·402	8·17	·350	·250	1·10	3·61	1·24	·78
11	,, ,, $\frac{3}{8}$	2·859	9·72	·350	·250	1·12	4·26	1·48	·78
11	,, ,, $\frac{1}{2}$	3·749	12·75	·350	·250	1·17	5·46	1·93	·77
11	,, ,, $\frac{5}{8}$	4·609	15·67	·350	·250	1·22	6·56	2·36	·77

This table has been taken by permission from Messrs. Dorman, Long & Co.'s *Pocket Companion*. An additional British Standard Angle, not included on this page, is:—BSEA 15—7″ × 7″ × ·5″ to ·675″.

British Standard Equal Angles.
Dimensions and Properties in Inch Units.

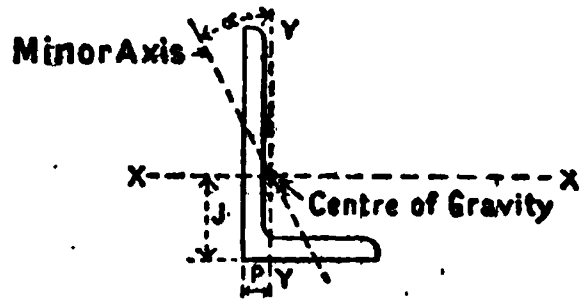
Reference Mark. BSEA.	Size and Thickness.	Area. Square Inches.	Weight per Foot-lbs.	Radii. Root.	Radii. Toe.	J Dimension.	XX Moment of Inertia.	XX Section Modulus.	Least Radius of Gyration.
10	3½ × 3½ × 5/16	2·091	7·11	·325	·225	·975	2·39	·95	·68
10	,, ,, 3/8	2·485	8·45	·325	·225	1·00	2·80	1·12	·68
10	,, ,, 1/2	3·251	11·05	·325	·225	1·05	3·57	1·46	·68
10	,, ,, 5/8	3·985	13·55	·325	·225	1·09	4·27	1·77	·68
9	3 × 3 × 1/4	1·44	4·90	·300	·200	·827	1·21	·56	·59
9	,, ,, 5/16	1·779	6·05	·300	·200	·853	1·47	·68	·58
9	,, ,, 3/8	2·111	7·18	·300	·200	·877	1·72	·81	·58
9	,, ,, 1/2	2·752	9·36	·300	·200	·924	2·19	1·05	·58
9	,, ,, 5/8	3·362	11·43	·300	·200	·970	2·59	1·28	·58
7	2½ × 2½ × 1/4	1·187	4·04	·275	·200	·703	·677	·38	·48
7	,, ,, 5/16	1·464	4·98	·275	·200	·728	·822	·46	·48
7	,, ,, 3/8	1·733	5·89	·275	·200	·752	·962	·55	·48
7	,, ,, 1/2	2·249	7·65	·275	·200	·799	1·21	·71	·48
6	2¼ × 2¼ × 1/4	1·063	3·61	·250	·175	·643	·489	·30	·44
6	,, ,, 5/16	1·309	4·45	·250	·175	·668	·592	·37	·43
6	,, ,, 3/8	1·547	5·26	·250	·175	·692	·686	·44	·43
5	2 × 2 × 3/16	·715	2·43	·250	·175	·554	·260	·18	·39
5	,, ,, 1/4	·938	3·19	·250	·175	·581	·336	·24	·39
5	,, ,, 5/16	1·153	3·92	·250	·175	·605	·401	·29	·38
5	,, ,, 3/8	1·36	4·62	·250	·175	·629	·467	·34	·38
4	1¾ × 1¾ × 3/16	·622	2·11	·225	·150	·495	·172	·14	·34
4	,, ,, 1/4	·814	2·77	·225	·150	·520	·220	·18	·34
4	,, ,, 5/16	·997	3·39	·225	·150	·544	·264	·22	·34
3	1½ × 1½ × 3/16	·526	1·79	·200	·150	·434	·105	·10	·29
3	,, ,, 1/4	·686	2·33	·200	·150	·458	·134	·13	·29
3	,, ,, 5/16	·839	2·85	·200	·150	·482	·159	·16	·29
2	1¼ × 1¼ × 3/16	·433	1·47	·200	·150	·371	·058	·07	·24
2	,, ,, 1/4	·561	1·91	·200	·150	·396	·073	·09	·23

See note on preceding page. Additional British Standard Angles, not included in this page, are:—BSEA 8—2¾″ × 2¾″ × ¼″ to ½″; and BSEA 1—1″ × 1″ × ⅛″ to ¼″.

British Standard Unequal Angles.

Dimensions and Properties in Inch Units.

Fig. 155.



Reference Mark. BSUA.	Size and Thickness.	Area Square Inches.	Weight per Foot-lbs.	Radii. Root.	Radii. Toe.	Dimensions. J	Dimensions. P	Moments of Inertia. About XX.	Moments of Inertia. About YY.	Section Moduli. About XX.	Section Moduli. About YY.	Angle ∝ Degrees.	Least Radius of Gyration.
25	7 × 3½ × 3/8	3·797	12·91	·425	·30	2·45	·713	19·30	3·32	4·24	1·19	15	·75
25	,, ,, [illegible]	5·000	17·00	·425	·30	2·50	·764	25·1	4·28	5·58	1·56	14½	·74
25	,, ,, [illegible]	6·172	20·98	·425	·30	2·55	·814	30·55	5·15	6·86	1·92	14½	·74
25	,, ,, [illegible]	7·313	24·86	·425	·30	2·60	·862	35·68	5·95	8·11	2·26	14	·73
24	6½ × 4½ × [illegible]	3·982	13·54	·45	·325	2·03	1·04	17·08	6·76	3·82	1·95	25½	·98
24	,, ,, [illegible]	5·248	17·84	·45	·325	2·08	1·09	22·2	8·75	5·02	2·57	25	·97
24	,, ,, [illegible]	6·482	22·04	·45	·325	2·13	1·14	27·09	10·60	6·20	3·15	25	·96
24	,, ,, [illegible]	7·686	26·13	·45	·325	2·18	1·19	31·66	12·32	7·33	3·72	25	·96
22	6½ × 3½ × [illegible]	3·610	12·27	·425	·30	2·22	·741	15·7	3·27	3·67	1·18	16½	·75
22	,, ,, [illegible]	4·750	16·16	·425	·30	2·28	·792	20·4	4·20	4·83	1·55	16½	·75
22	,, ,, [illegible]	5·860	19·92	·425	·30	2·33	·841	24·83	5·06	5·95	1.90	16	·74
21	6 × 4 × [illegible]	3·610	12·27	·425	·30	1·91	·923	13·2	4·73	3·23	1·54	23½	·87
21	,, ,, [illegible]	4·750	16·16	·425	·30	1·96	·974	17·1	6·10	4·23	2·02	23½	·86
21	,, ,, [illegible]	5·860	19·92	·425	·30	2·02	1·02	20·8	7·36	5·23	2·47	23½	·85
21	,, ,, [illegible]	6·938	23·59	·425	·30	2·06	1·07	24·21	8·52	6·15	2·91	23	·85
20	6 × 3½ × [illegible]	3·424	11·64	·40	·275	2·01	·773	12·6	3·22	3·16	1·18	19	·76
20	,, ,, [illegible]	4·502	15·31	·40	·275	2·06	·823	16·4	4·14	4·16	1·55	19	·75
20	,, ,, [illegible]	5·549	18·87	·40	·275	2·11	·872	19·88	4·97	5·11	1·89	18½	·75
20	,, ,, [illegible]	6·564	22·32	·40	·275	2·16	·919	23·14	5·74	6·03	2·22	18	·74
19	5½ × 3½ × [illegible]	3·236	11·00	·40	·275	1·80	·807	9·93	3·15	2·68	1·17	22	·76
19	,, ,, [illegible]	4·252	14·46	·40	·275	1·85	·857	12·80	4·05	3·51	1·53	22	·75
19	,, ,, [illegible]	5·236	17·80	·40	·275	1·90	·905	15·6	4·86	4·33	1·87	21½	·75
18	5½ × 3 × 5/16	2·562	8·71	·375	·25	1·87	·636	8·00	1·72	2·20	·73	17	·65
18	,, ,, [illegible]	3·050	10·37	·375	·25	1·90	·662	9·45	2·02	2·62	·86	17	·64
18	,, ,, [illegible]	4·003	13·61	·375	·25	1·95	·711	12·2	2·58	3·44	1·13	16½	·64
18	,, ,, [illegible]	4·925	16·74	·375	·25	2·00	·759	14·7	3·08	4·20	1·37	16½	·63
17	5 × 4 × [illegible]	3·236	11·00	·40	·275	1·51	1·01	7·96	4·53	2·28	1·52	32	·85
17	,, ,, [illegible]	4·252	14·46	·40	·275	1·56	1·06	10·3	5·82	2·99	1·98	32	·84
17	,, ,, [illegible]	5·236	17·80	·40	·275	1·60	1·11	12·4	7·01	3·66	2·43	32	·83
16	5 × 3½ × 5/16	2·562	8·71	·375	·25	1·56	·822	6·47	2·63	1·88	·98	25½	·76
16	,, ,, [illegible]	3·050	10·37	·375	·25	1·59	·848	7·64	3·09	2·24	1·17	25½	·75
16	,, ,, [illegible]	4·003	13·61	·375	·25	1·64	·897	9·86	3·96	2·93	1·52	25½	·75
16	,, ,, [illegible]	4·925	16·74	·375	·25	1·69	·944	11·9	4·75	3·60	1·86	25	·74

This table has been taken by permission from Messrs. Dorman, Long & Co.'s *Pocket Companion*. An additional British Standard Angle, not included on this page, is:—BSUA 23—6½″ × 4″ × ·525″.

British Standard Unequal Angles.

Dimensions and Properties in Inch Units.

Reference Mark. BSUA.	Size and Thickness.	Area. Square Inches.	Weight per Foot-lbs.	Radii. Root.	Radii. Toe.	Dimensions. J	Dimensions. P	Moments of Inertia. About XX.	Moments of Inertia. About YY.	Section Moduli. About XX.	Section Moduli. About YY.	Angle θ Degrees.	Least Radius of Gyration.
15	5 × 3 × 5/16	2·402	8·17	·35	·25	1·66	·667	6·14	1·68	1·84	·72	20	·65
15	,, ,,	2·859	9·72	·35	·25	1·68	·693	7·24	1·97	2·18	·85	19½	·65
15	,, ,,	3·749	12·75	·35	·25	1·73	·742	9·33	2·51	2·85	1·11	19½	·64
15	,, ,,	4·609	15·67	·35	·25	1·78	·789	11·25	3·00	3·49	1·36	19	·64
14	4½ × 3½ × 5/16	2·402	8·17	·35	·25	1·36	·866	4·82	2·55	1·54	·97	30½	·74
14	,, ,,	2·859	9·72	·35	·25	1·39	·891	5·69	3·00	1·83	1·15	30½	·74
14	,, ,,	3·749	12·75	·35	·25	1·44	·940	7·31	3·84	2·39	1·5	30	·74
14	,, ,,	4·609	15·67	·35	·25	1·48	·987	8·81	4·61	2·92	1·83	30	·74
12	4 × 3½ × 5/16	2·216	7·64	·35	·25	1·16	·915	3·46	2·47	1·22	·96	37	·72
12	,, ,,	2·671	9·08	·35	·25	1·19	·941	4·08	2·90	1·45	1·13	37	·72
12	,, ,,	3·499	11·90	·35	·25	1·24	·990	5·23	3·71	1·89	1·48	37	·71
12	,, ,,	4·296	14·61	·35	·25	1·28	1·04	6·28	4·44	2·31	1·80	36½	·71
11	4 × 3 × 5/16	2·091	7·11	·325	·225	1·24	·746	3·31	1·59	1·20	·71	28½	·64
11	,, ,,	2·485	8·45	·325	·225	1·27	·771	3·89	1·87	1·42	·84	28½	·64
11	,, ,,	3·251	11·05	·325	·225	1·31	·819	4·98	2·37	1·85	1·09	28½	·63
11	,, ,,	3·985	13·55	·325	·225	1·36	·865	5·96	2·83	2·26	1·33	28	·63
10	4 × 2½ × [illegible]	1·563	5·31	·325	·225	1·30	·561	2·54	·767	·94	·40	21	·54
10	,, ,, 5/16	1·934	6·58	·325	·225	1·33	·587	3·11	·935	1·16	·49	21	·54
10	,, ,,	2·298	7·81	·325	·225	1·35	·612	3·65	1·09	1·38	·58	21	·53
10	,, ,,	3·001	10·20	·325	·225	1·40	·660	4·66	1·38	1·79	·75	20½	·53
9	3½ × 3 × 5/16	1·934	6·58	·325	·225	1·04	·792	2·27	1·53	·92	·69	35½	·62
9	,, ,,	2·298	7·81	·325	·225	1·07	·819	2·67	1·80	1·10	·83	35½	·62
9	,, ,,	3·001	10·20	·325	·225	1·11	·867	3·40	2·28	1·42	1·07	35½	·61
9	,, ,,	3·673	12·49	·325	·225	1·16	·912	4·05	2·71	1·73	1·30	35	·61
8	3½ × 2½ × [illegible]	1·44	4·90	·30	·20	1·10	·603	1·76	·748	·73	·39	26½	·54
8	,, ,, 5/16	1·779	6·05	·30	·20	1·12	·627	2·15	·910	·90	·49	26½	·54
8	,, ,,	2·111	7·18	·30	·20	1·15	·652	2·52	1·06	1·07	·57	26	·53
8	,, ,,	2·752	9·36	·30	·20	1·20	·699	3·20	1·34	1·39	·74	26	·53
7	3 × 2½ × [illegible]	1·312	4·46	·275	·20	·895	·648	1·14	·716	·54	·39	34	·52
7	,, ,, 5/16	1·62	5·51	·275	·20	·921	·673	1·39	·871	·67	·48	34	·52
7	,, ,,	1·921	6·53	·275	·20	·945	·697	1·62	1·02	·79	·57	34	·52
7	,, ,,	2·499	8·50	·275	·20	·992	·744	2·05	1·28	1·02	·73	33½	·52
6	3 × 2 × [illegible]	1·187	4·04	·275	·20	·976	·482	1·06	·373	·52	·25	23½	·43
6	,, ,, 5/16	1·464	4·98	·275	·20	1·00	·508	1·29	·452	·65	·30	23	·42
6	,, ,,	1·733	5·89	·275	·20	1·03	·532	1·50	·525	·76	·36	23	·42
6	,, ,,	2·249	7·65	·275	·20	1·07	·578	1·89	·656	·98	·46	22½	·42
5	2½ × 2 × [illegible]	1·063	3·61	·25	·175	·774	·527	·636	·359	·37	·24	32	·42
5	,, ,, 5/16	1·309	4·45	·25	·175	·799	·552	·770	·433	·45	·30	31½	·42
5	,, ,,	1·547	5·26	·25	·175	·823	·575	·895	·502	·53	·35	31½	·42
4	2 × 1½ × 3/16	·602	2·11	·225	·150	·627	·381	·240	·115	·17	·10	28½	·32
4	,, ,,	·814	2·77	·225	·150	·653	·407	·308	·146	·23	·13	28	·31
4	,, ,, 5/16	·987	3·39	·225	·150	·678	·431	·369	·174	·28	·16	28	·31

See note on preceding page. Additional British Standard Angles, not included on this page, are:—BSUA 13—4½″ × 3″ × ·3″ to ·5″; BSUA 3—1¾″ × 1¾″ × ·175″ to ·3″; BSUA 2—1½″ × 1½″ × ⅛″ to ¼″; BSUA 1—1½″ × 1″ × ⅛″ to ¼″.

British Standard Bulb Angles.
Dimensions and Properties in Inch Units.

Fig. 156.

a

x

Y

Reference Mark. BSBA.	Size A × B.	Standard Thickness. T.	Area. Square Inches.	Weight per Foot-lbs.	Radii. r^1.	r^2.
20	12 × 4	·600	10·724	36·46	·675	·450
19	11 × 3½	·550	8·953	30·44	·625	·425
18	10 × 3½	·525	7·904	26·87	·575	·400
17	9½ × 3½	·500	7·277	24·74	·550	·375
16	9 × 3½	·475	6·677	22·70	[illegible]	·350
15	9 × 3	·475	6·439	21·89	[illegible]	·350
14	8½ × 3½	·475	6·339	21·55	·525	·350
13	8½ × 3	·450	5·837	19·85	[illegible]	·350
12	8 × 3½	·450	5·779	19·65	·500	·325
11	8 × 3	·425	5·301	18·02	·500	·325
10	7½ × 3½	·425	5·236	17·80	·475	·325
9	7½ × 3	·425	5·023	17·08	·475	·325
8	7 × 3½	·425	4·940	16·80	·450	·300
7	7 × 3	·400	4·498	15·29	·450	·300
6	6½ × 3½	·400	4·420	15·03	·425	·275
5	6½ × 3	·375	4·002	13·61	·425	·275
4	6 × 3	·375	3·763	12·79	·400	·275
3	5½ × 3	·350	3·392	[illegible]	·375	·250
[illegible]	5 × 2½	·325	2·743	9·33	·350	·250
1	4 × 2½	·300	2·170	7·38	·300	·200

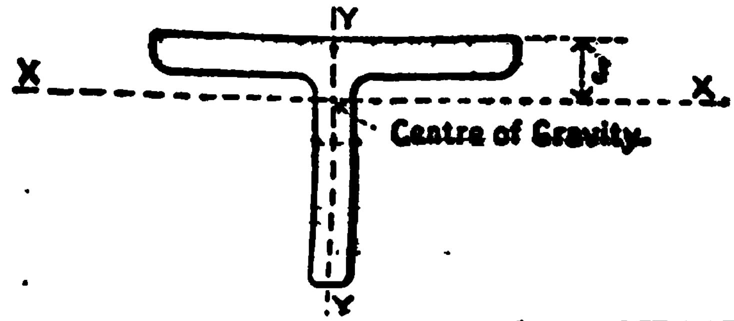
The properties of British Standard Sections in above tables are published by permission of the Engineering Standards Committee.

British Standard Bulb Angles.

Dimensions and Properties in Inch Units.

Radii.			Centre of Gravity.		Moments of Inertia.		Section Moduli.		Angle ∝ Degrees.	Least Radius of Gyration. Inches.	Reference Mark.
r^3	r^4	r^5	J	P	About XX	About YY	About XX	About YY			BSBA.
1·125	·675	·550	5·585	·778	191·443	8·355	29·843	2·593	4½	·821	20
1·050	·625	·525	5·188	·686	133·856	5·170	23·031	1·837	4	·715	19
·975	·575	·500	4·622	·693	98·228	4·828	18·265	1·720	5	·724	18
·950	·550	·475	4·361	·694	82·418	4·585	16·038	1·634	5½	·729	17
·900	·550	·450	4·095	·695	66·383	4·336	13·941	1·546	6	·735	16
·900	·550	·450	4·238	·603	64·712	2·792	13·589	1·165	4	·618	15
·850	·525	·425	3·798	·706	57·725	4·265	12·277	1·526	7	·740	14
·850	·525	·425	3·956	·598	52·685	2·603	11·594	1·084	5	·621	13
·825	·500	·400	3·543	·712	47·072	4·031	10·561	1·446	8	·746	12
·825	·500	·400	3·698	·600	42·863	2·449	9·964	1·020	5½	·627	11
·800	·475	·400	3·290	·717	37·824	3·772	8·984	1·355	8¾	·750	10
·800	·475	·400	3·419	·612	35·725	2·405	8·754	1·007	6	·632	9
·750	·450	·375	2·998	·737	30·914	3·780	7·725	1·350	10	·758	8
·750	·450	·375	3·141	·614	28·063	2·250	7·272	·943	7	·638	7
·700	·425	·350	2·723	·747	23·943	3·494	6·339	1·269	11½	·764	6
·700	·425	·350	2·865	·619	21·677	2·098	5·963	·881	8½	·644	5
·675	·400	·325	2·597	·638	17·350	2·057	5·098	·871	10	·648	4
·650	·375	·325	2·346	·649	13·032	1·909	4·132	·812	11½	·653	3
·600	·350	·300	2·193	·538	8·802	1·021	3·136	·520	9½	·540	2
·525	·300	·250	1·661	·577	4·461	·915	1·907	·476	14¾	·548	1

British Standard Tees.
Dimensions and Properties in Inch Units.



Reference Mark. BST.	Size and Thickness.	Area. Square Inches.	Weight per Foot-lbs.	Radii. Table Root.	Radii. Table Toe.	J Dimension.	Moments of Inertia. About XX	Moments of Inertia. About YY	Section Moduli. About XX	Section Moduli. About YY	Radii of Gyration. About XX	Radii of Gyration. About YY
21	6 × 4 × 3/8	3·634	12·36	·425	·300	·915	4·700	6·344	1·52	2·11	1·137	1·321
21	,, ,, 1/2	4·771	16·22	·425	·300	·968	6·070	8·621	2·00	2·87	1·128	1·344
21	5/8	5·878	19·99	·425	·300	1·02	7·350	10·912	2·47	3·64	1·118	1·362
20	6 × 3 × 3/8	4·272	14·53	·400	·275	·684	2·635	8·649	1·14	2·88	·785	1·423
20	,, ,, 1/2	5·256	17·87	·400	·275	·732	3·144	10·938	1·39	3·65	·773	1·443
19	5 × 4 × 3/8	3·257	11·07	·400	·275	·998	4·471	3·691	1·49	1·48	1·172	1·065
19	,, ,, 1/2	4·268	14·51	·400	·275	1·05	5·772	5·017	1·96	2·01	1·163	1·084
17	5 × 3 × 3/8	2·875	9·78	·350	·250	·691	1·973	3·716	·85	1·49	·828	1·137
17	,, ,, 1/2	3·762	12·79	·350	·250	·741	2·516	5·031	1·11	2·01	·818	1·156
15	4 × 4 × 3/8	2·872	9·77	·350	·250	1·11	4·189	1·901	1·45	·95	1·208	·814
15	,, ,, 1/2	3·758	12·78	·350	·250	1·16	5·402	2·590	1·90	1·29	1·199	·830
14	4 × 3 × 3/8	2·498	8·49	·325	·225	·767	1·860	1·914	·83	·96	·863	·875
14	,, ,, 1/2	3·262	11·08	·325	·225	·816	2·365	2·599	1·08	1·30	·851	·893
13	3½ × 3½ × 3/8	2·496	8·49	·325	·225	·988	2·768	1·284	1·10	·73	1·053	·717
13	,, ,, 1/2	3·259	11·08	·325	·225	1·04	3·543	1·752	1·44	1·00	1·043	·733
11	3 × 3 × 3/8	2·121	7·21	·300	·200	·868	1·708	·816	·80	·54	·897	·620
11	,, ,, 1/2	2·76	9·38	·300	·200	·918	2·165	1·115	1·04	·74	·886	·636
10	3 × 2½ × 3/8	1·929	6·56	·275	·200	·695	1·015	·814	·56	·54	·725	·650
10	,, ,, 1/2	2·506	8·52	·275	·200	·742	1·275	1·109	·73	·74	·713	·665
8	2½ × 2½ × 1/4	1·197	4·07	·275	·200	·697	·677	·302	·38	·24	·752	·502
8	,, ,, 5/16	1·474	5·01	·275	·200	·724	·823	·387	·46	·31	·747	·512
8	3/8	1·742	5·92	·275	·200	·750	·959	·473	·55	·38	·742	·521
7	2¼ × 2¼ × 1/4	1·071	3·64	·250	·175	·638	·488	·224	·30	·20	·675	·457
7	,, ,, 3/8	1·554	5·28	·250	·175	·689	·685	·349	·44	·31	·664	·474
6	2 × 2 × 1/4	·947	3·22	·250	·175	·579	·337	·157	·24	·16	·597	·407
6	,, ,, 3/8	1·367	4·64	·250	·175	·628	·469	·246	·34	·25	·586	·424
5	1½ × 2 × 1/4	·820	2·79	·225	·150	·648	·307	·068	·23	·09	·612	[illegible]
5	,, ,, 5/16	1·003	3·41	·225	·150	·674	·369	·088	·28	·12	·607	[illegible]
4	1¾ × 1¾ × 1/4	·820	2·79	·225	·150	·519	·221	·107	·18	·12	·520	·361
4	,, ,, 5/16	·999	3·40	·225	·150	·544	·265	·137	·22	·16	·515	·370
3	1½ × 1½ × 3/16	·531	1·81	·200	·150	·435	·106	·048	·10	·06	·447	·301
3	,, ,, 1/4	·692	2·35	·200	·150	·460	·135	·067	·13	·09	·442	·312

The properties of British Standard Sections in above table are published by permission of the Engineering Standards Committee, and of Messrs. Dorman, Long & Co., from whose *Pocket Companion* this table has been copied. Other sections included in the complete BS list, but not shown here, are :—BST, 22—7″ × 3½″ × ½″; BST, 18—5″ × 3½″ × ½″; BST, 16—4″ × 5″ × ⅜″ to ½″; BST, 12—3″ × 4″ × ⅜″ to ½″; BST, 9—3″ × 2″ × 5/16″ to ⅜″; BST, 2—1¼″ × 1¼″ × ⅛″ to 3/16″; BST, 1—1″ × 1″ × ⅛″ to 3/16″.

BRITISH STANDARD BULB TEES.

DIMENSIONS AND PROPERTIES IN INCH UNITS.

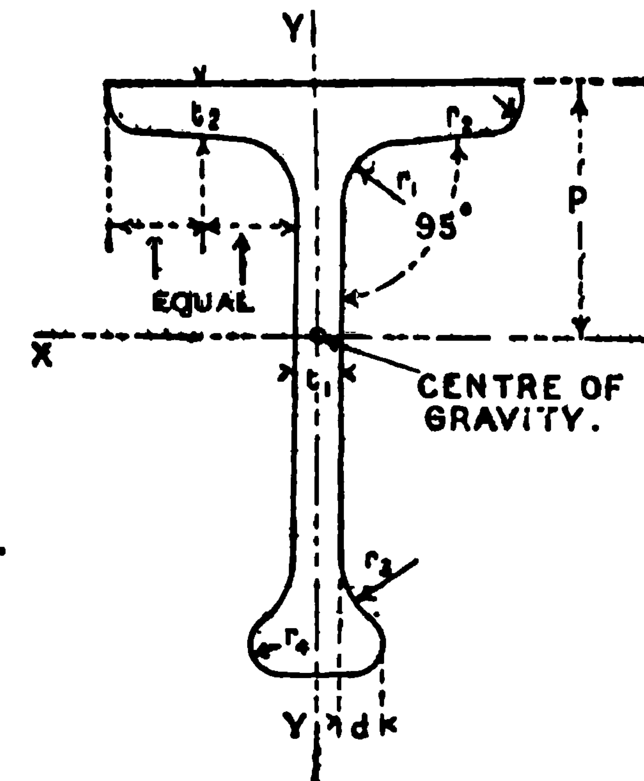


FIG. 157.

Reference Mark.	Size.		Standard Thickness.		d.	Radii.				Weight per Foot-lb.	Sectional Area.	Centre of Gravity. Dimension.	Moments of Inertia.		Section Moduli.		Least Radius of Gyraion.
BSBT.	Depth.	Width.	t_1	t_2		r_1	r_2	r_3	r_4			P	About XX	About YY	About XX	About YY	
1	7 ×	5	·425	·425	·450	·600	·200	·800	·300	19·01	5·592	2·611	35·087	4·021	7·994	1·608	·848
2	8 ×	5½	·450	·450	·500	·675	·225	·900	·325	22·78	6·701	3·018	55·377	5·628	11·115	2·046	·916
3	9 ×	5½	·475	·500	·575	·750	·250	1·000	·375	26·76	7·870	3·524	83·780	6·410	15·290	2·331	·902
4	10 ×	6	·500	·550	·625	·825	·275	1·100	·400	31·60	9·295	3·881	122·278	9·124	19·984	3·041	·991
5	11 ×	6½	·550	·600	·675	·900	·300	1·200	·450	37·86	11·136	4·290	177·041	12·690	26·324	3·905	1·067
6	12 ×	6½	·575	·650	·725	·925	·325	1·300	·475	42·49	12·498	4·759	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

British Standard Z Bars.

Dimensions and Properties in Inch Units.

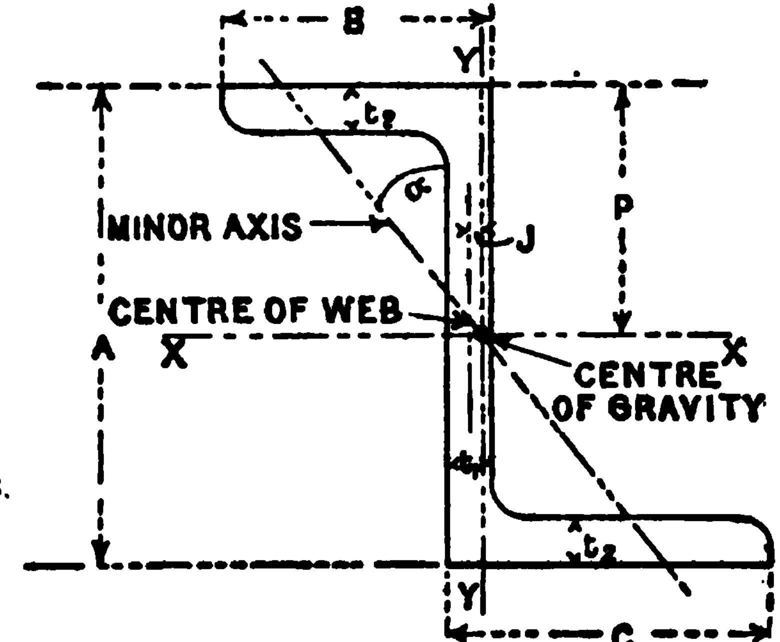


Fig. 158.

Reference Mark.	Size. A×B×C.	Standard Thickness.		Radii.		Weight per Foot-lb.	Sectional Area.	Centre of Gravity.		Moments of Inertia.		Section Moduli.		Angle α Degrees.	Least Radius of Gyration.
BSZ.		t_1	t_2	r_1	r_2			Right of Centre = J.	Below Centre = P − A/2	About XX	About YY	About XX	About YY		
1	3 × 2½ × 3	·300	·400	·325	·225	9·81	2·884	·090	·178	4·009	4·591	2·521	1·718	42½	·543
2	4 × 2½ × 3	·325	·425	·350	·225	11·53	3·392	·112	·160	8·368	4·831	3·962	1·805	35¼	·622
3	5 × 3 × 3	·350	·450	·375	·250	14·17	4·169	—	—	16·145	6·578	6·458	2·328	29½	·698
4	6 × 3½ × 3½	·375	·475	·425	·300	17·88	5·258	—	—	29·660	11·184	9·887	3·361	28¼	·821
5	7 × 3½ × 3½	·400	·500	·450	·300	20·22	5·948	—	—	44·609	11·618	12·745	3·521	23¼	·840
6	8 × 3½ × 3½	·425	·525	·450	·325	22·68	6·670	—	—	63·729	12·024	15·932	3·657	19¼	·845
7	9 × 3½ × 3½	·450	·550	·475	·350	25·33	7·449	—	—	87·889	12·418	19·531	3·792	16½	·843
8	10 × 3½ × 3½	·475	·575	·500	·350	28·16	8·283	—	—	117·865	12·876	23·573	3·947	14	·839

The Properties of British Standard Sections in above table are published by permission of the Engineering Standards Committee.

NOTES ON MATERIALS.

(*For tests see pp.* 263 *to* 285.)

IRON-ORE.

Iron-ore is found principally in the following conditions:—

Name.	*Composition.*	*Percentage of Iron.*
Magnetic	Fe_3O_4	72
Specular ore or red hæmatite	Fe_2O_3	70
Brown hæmatite	$2(Fe_2O_3) \cdot 3H_2O$	60
Spathic iron-ore	$FeCO_3$	48
Clay ironstone	$FeCO_3$ and clay	17–48
Iron pyrites	FeS_2	46

Clay ironstone is the principal source of iron in England.

PIG IRON.

This is produced from the ore by heating it with a suitable flux in a blast furnace. It is graded according to its appearance. The darkest grey iron is termed No. 1, then the lighter irons are termed Nos. 2, 3, 4 (foundry), 4 (forge), mottled, and white. The white iron has a hard silvery-white fracture, and is extremely brittle. The mottled and No. 4 (forge) are used for the manufacture of wrought iron, the remaining numbers being used for making cast iron. The percentages of carbon are as follows:—

	Grey.	*Mottled.*	*White.*
Graphite . . .	3·4 ...	2·2 ...	0·1
Combined Carbon .	0·1 ...	1·4 ...	3·2

CAST IRON.

Produced by melting down and purifying pig iron. It is a material having great compressive strength (40 tons per square inch) but weak in tension or under shear, and lacking in ductility. Its properties are greatly influenced by the presence of minute quantities of silicon, phosphorus, and manganese.

Grey cast iron is the most suitable for small castings where fine definition is required, but not great strength. *White or light-grey cast iron* is used for large castings.

MALLEABLE CAST IRON.

Ordinary iron castings are heated in contact with iron oxide; the material of the casting is thus rendered malleable and much less brittle. A special quality, made by the "Blackheart" system, is much superior and is used for castings requiring moderate tensile or pressure tests.

WROUGHT IRON.

Is nearly pure iron, produced by abstracting the greater portion of the carbon from cast iron.

The puddling process, which is that generally employed, consists of heating the cast iron (fairly white) with a basic slag which oxidizes and removes the principal impurities. The iron obtained is hammered and rolled. It is then cut up,

piled, re-heated, and again rolled. In the best qualities (No. 3) this process is again repeated.

Wrought iron is extremely ductile and malleable, and can be readily welded. It cannot be greatly hardened by quenching like steel. It has a fair tensile strength.

The longitudinal strength is increased by rolling, and the tensile is greater with the grain than across.

Strength and toughness are indicated by a fine close-grain uniform fibrous structure, free from all appearance of crystallization, with a clear bluish-grey colour and silky lustre on a torn surface; its tenacity is not appreciably diminished at a temperature of 395° Fahrenheit, but at a dull red heat it is reduced to about three-fourths.

Steel.

A compound of iron with from ·1 to 1·5 per cent of carbon; the varieties containing less carbon can be welded and forged (although not so readily as wrought iron), and are termed mild steel, and used for plates and forgings. The presence of manganese increases the toughness and makes it easier to weld.

Bessemer steel is produced by removing the carbon by a strong blast from molten cast iron, leaving mainly pure iron, into which a certain amount of carbon and manganese is introduced by adding spiegeleisen.

The metal is then run into large ingots, and hammered and rolled like wrought iron.

When fractured slowly it presents a silky fibrous appearance, but if suddenly a granular appearance, nearly free of lustre and unlike the brilliant crystalline appearance of iron.

The open-hearth process is now usually employed for making mild steel and certain qualities of cast steel. A mixture of pig iron and heavy scrap are heated together in a reverberatory furnace. The addition of pure hæmatite completes the process of oxidation. Ferro-manganese (mild steel) or spiegeleisen (hard steel) is finally added.

Cast Steel has a high tensile strength; castings must be carefully annealed to avoid excessive brittleness.

Quenching steel is the process of hardening it by heating it to a sufficiently high temperature (depending on the quality —about 700° C.) and then suddenly cooling by quenching.

Tempering consists of re-heating a quenched steel to a moderate temperature, and then quenching in water or oil. The hard steel is softened or tempered by this process; oil softens more than water. The temperatures and colours for tempering are :—

Razors, taps, dies, etc.	Straw.	230° C.
Punches, chisels, etc. .	Purple.	275° C.
Swords, springs, etc.	Light blue.	288° C.
Hand saws . . .	Nearly black.	316° C.

Annealing is heating to a low red heat, and then cooling very slowly, e.g. under ashes. This removes the internal stresses set up in castings or in mild steel after much working or punching.

Copper.

Very tough and elastic, of considerable strength, malleable and ductile, suitable for hammering into forms requiring strength and elasticity combined with lightness, but does not make good castings.

It is hardened by hammering or rolling, but can be restored to its normal condition by annealing, which is performed by heating and quenching. It is easily brazed, and mixed with other metals it forms very valuable alloys, and corrodes but little under the action of sea water.

Tin.

Very malleable but only slightly ductile, and when bent gives a peculiar cracking noise. Principally used with other metals to form alloys, or as a protective covering to other metals liable to rust, as it is little affected by the action of the air or weak acids.

Zinc.

Brittle when cold, malleable when hot. Forms with other metals valuable alloys. It is little affected by the air or weak acids generally, and is therefore much used in coating metals to protect them from the action of the air or sea water.

Bronze or Gun Metal.

Strictly an alloy of copper and tin, but a little zinc is often added to increase the fusibility. Tin increases the hardness and mixes well in all proportions. With 2 parts of copper to 1 of tin an alloy is formed which cannot be cut with steel tools.

Gunmetal cannot be rolled owing to the high proportion of tin; but it is much used in the form of castings.

Brass.

An alloy of copper and zinc, with a small quantity of tin sometimes added to increase the hardness or vary the colour.

Lead may be added to increase the ductility and make it more suitable for turning or filing. It is very malleable and easily worked cold, but not fit for forging at a red heat.

A good mixture for fine or yellow brass is 2 parts copper, 1 part zinc; used for ornamental castings, &c.

Admiralty brass must contain at least 63 per cent. of copper, and not more than 3½ per cent. of lead.

Muntz's Metal.

Composed of 3 parts copper and 2 parts zinc. Has a very high tenacity, very ductile, and can be forged hot, and if hammered or rolled cold can be used for springs.

Much used for sheathing ships, and for engine bolts, &c., liable to rust.

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di[illegible]
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fe[illegible]

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[illegible] and

[illegible]

Quality.	*Yield stress. tons / in.*^{2}	*Ultimate strength. tons / in.*^{2}	*Percentage elongation on*
A	19·3	28·4	18
B	15·0	28·5	24
C	29·0	37·2	5
D	26·0	38·1	2

TABLE OF ALLOYS.

ALLOY	Component Parts			
	Copper	Tin	Zinc	Brass
Soft gun-metal	16	1	—	—
Metal for toothed wheels	$10\frac{3}{4}$	1	—	—
" " "	16	$2\frac{1}{2}$	—	2
Hard bearings for machinery	8	1	—	—
Gun metal, Admiralty	88	10	2	—
Speculum metal	$2\frac{1}{2}$	1	—	—
Sound copper castings	1	—	32	—
Tombac, or red brass	8	—	1	—
Red sheet brass	$5\frac{1}{4}$	—	1	—
Brass that solders well	$2\frac{3}{8}$	—	1	—
Ordinary brass	2	—	1	—
Muntz metal	$1\frac{1}{2}$	—	1	—
Extremely tenacious metal	16	$1\frac{1}{2}$	$\frac{1}{2}$	—
Bearings to stand great strains	16	$2\frac{1}{2}$	$\frac{1}{3}$	—
Extremely hard metal	16	$2\frac{1}{2}$	$2\frac{1}{2}$	—
Government standard metal	144	$14\frac{3}{4}$	—	12
Articles for turning	—	2	—	$1\frac{1}{2}$
Bearings, nuts, &c.	—	$2\frac{1}{2}$	—	$1\frac{1}{2}$
Bell metal	16	5	—	—
Statuary bronze	90	2	5	—

TABLE OF SOLDERS.

SOLDERS	Component Parts					Flux
	Copper	Tin	Lead	Zinc	Bismuth	
Coarse solder for plumbers	—	1	3	—	—	Resin
Fine solder for plumbers	—	1	2	—	—	"
Solder for tin	—	$1\frac{1}{2}$	1	—	—	" or chloride of zinc
" pewter	—	3	4	—	2	" "
" bismuth	—	2	2	—	1	" "
Brazing, soft	4	1	—	3	—	Sal ammoniac or chloride of zinc
" hard	1	—	—	1	—	Sal ammoniac or chloride of zinc
" hardest	3	—	—	1	—	Sal ammoniac or chloride of zinc

NAVAL BRASS.

Is Muntz's metal with about 1 per cent. of tin added. Resists the action of sea water whilst retaining all the other properties.

Can be forged hot, has a very high tenacity. It can be rolled into bars, and is used for bolts and studs where a non-rusting material is required.

Admiralty composition, 62 per cent. of copper, 37 per cent. of zinc, and 1 per cent. of tin.

PHOSPHOR BRONZE.

Very hard, tough, close-grained alloy, composed of copper and tin with a small amount of phosphorus.

Very superior for bearings, wheels, etc., but if made hot is liable to crack.

Admiralty composition for bolts, etc., 90 per cent. copper, and 10 per cent. phosphor tin containing about 5 per cent. of phosphorus.

MANGANESE BRONZE.*

Very uniform close-grained bronze, with a proportion of ferro-manganese; can be rolled either hot or cold, very tough and strong, largely used for propeller blades, etc.

ALUMINIUM BRONZE.

Has nearly double the tenacity of gun metal, is not liable to rust, and can be forged either hot or cold; composed of 90 parts copper and 10 parts aluminium.

BABBIT'S WHITE METAL.

Used for bearings; composed of 10 parts tin, 1 copper, and 1 antimony.

FENTON'S WHITE METAL.

Used for stern bushes, bushes for paddle wheels, etc.; fairly tough and hard, contains 8 parts zinc, 1·66 tin, and ·44 copper.

CHROME-VANADIUM STEEL.

Contains 1 per cent chromium and ·15 per cent vanadium. Tensile strength 50 tons per square inch. Used for springs and for the protection of ships in lieu of thin armour.

PROPERTIES OF LIGHT ALLOY 'DURALUMIN' (HARD DRAWN).

(Dr. Walter Rosenhain.)

Specific gravity 2·8; weight per cubic foot 175 lb.; Young's modulus, 4,650 tons per square inch. Composition—copper 4·6 per cent, iron ·5 per cent, manganese ·5 per cent; magnesium ·5 per cent; silicon ·5 per cent; aluminium 93·4 per cent.

* This material resembles brass rather than bronze in its working qualities.

Quality.	*Yield stress. tons / in.²*	*Ultimate strength. tons / in.²*	*Percentage elongation on 2".*
A	19·3	28·4	18
B	15·0	28·5	24
C	29·0	37·2	5
D	26·0	38·1	2

Table of Alloys.

Alloy	Component Parts			
	Copper	Tin	Zinc	Brass
Soft gun-metal	16	1	—	—
Metal for toothed wheels	$10\frac{3}{4}$	1	—	—
" " "	16	$2\frac{1}{2}$	—	2
Hard bearings for machinery	8	1	—	—
Gun metal, Admiralty	88	10	2	—
Speculum metal	$2\frac{1}{2}$	1	—	—
Sound copper castings	1	—	32	—
Tombac, or red brass	8	—	1	—
Red sheet brass	$5\frac{1}{4}$	—	1	—
Brass that solders well	$2\frac{3}{8}$	—	1	—
Ordinary brass	2	—	1	—
Muntz metal	$1\frac{1}{2}$	—	1	—
Extremely tenacious metal	16	$1\frac{1}{2}$	$\frac{1}{2}$	—
Bearings to stand great strains	16	$2\frac{1}{2}$	$\frac{1}{2}$	—
Extremely hard metal	16	$2\frac{1}{2}$	$2\frac{1}{2}$	—
Government standard metal	144	$14\frac{3}{4}$	—	12
Articles for turning	—	2	—	$1\frac{1}{2}$
Bearings, nuts, &c.	—	$2\frac{1}{2}$	—	$1\frac{1}{2}$
Bell metal	16	5	—	—
Statuary bronze	90	2	5	—

Table of Solders.

Solders	Component Parts					Flux
	Copper	Tin	Lead	Zinc	Bismuth	
Coarse solder for plumbers	—	1	3	—	—	Resin
Fine solder for plumbers	—	1	2	—	—	"
Solder for tin	—	$1\frac{1}{2}$	1	—	—	" or chloride of zinc
" pewter	—	3	4	—	2	" "
" bismuth	—	2	2	—	1	" "
Brazing, soft	4	1	—	3	—	Sal ammoniac or chloride of zinc
" hard	1	—	—	1	—	Sal ammoniac or chloride of zinc
" hardest	3	—	—	1	—	Sal ammoniac or chloride of zinc

Table of the Weight and Strength of Materials.

Metals.

Name	Specific Gravity	Lbs. in a Cubic Foot	Tearing Force Lbs. on Sq. In.	Crushing Force Lbs. on Sq. In.	Modulus of Elasticity Lbs. on Sq. In.
Aluminium, cast	2·560	160·0	—	—	—
„ sheet	2·670	166·9	—	—	—
Antimony, cast	6·702	418·9	11,500	—	9,800 000
Arsenic	5·763	360·2	—	—	—
Bismuth, cast	9·822	613·9	2,798	—	—
Brass, cast	8·396	524·8	18,000	10,300	9,170,000
„ sheet	8·525	532·8	31,360	—	—
„ wire	8·544	533·0	49,000	—	14,230,000
Bronze	8·222	513·4	—	—	9,000,000
Cobalt, cast	7·811	488·2	—	—	—
Copper, bolts	8·850	581·3	36,000	—	—
„ cast	8·607	537·9	19,000	—	—
„ sheet	8·785	549·1	30,000	—	—
„ wire	8·878	548·6	60,000	—	17,000,000
Gold, pure	19·258	1203·6	20,400	—	—
„ hammered	19·362	1210·1	—	—	—
„ standard	17·647	1102·9	—	—	—
Gun metal	8·153	509·6	36,000	—	9,873,000
Iron, cast, from	6·955	434·7	13,400	82,000	14,000,000
„ „ to	7·295	455·9	29,000	145,000	22,900,000
„ „ average	7·125	445·3	16,500	112,000	17,000,000
„ wrought, from	7·560	472·5	50,000	40,300	—
„ „ to	7·800	487·5	68,000	32,000	—
„ „ average	7·680	480·0	60,000	36,000	28,000,000
Lead, cast	11·352	709·5	1,792	6,900	—
„ sheet	11·400	712·8	3,328	—	2 500,000
Mercury, fluid	13·568	848·0	—	—	—
„ solid	15·632	977·0	—	—	—
Muntz's metal	8·200	511·0	49,000	—	—
Nickel, cast	7·807	487·9	—	—	—
Pewter	11·600	702·5	—	—	—
Phosphor bronze	8·600	536·8	58,000	—	—
Platinum, pure	19·500	1218·8	—	—	—
„ sheet	20·337	1271·0	265,000	—	24,240,000
Silver, pure	10·474	654·6	42,000	—	—
„ standard	10·534	658·4	—	—	—
Steel, cast	7·829	489·3	58,240 to 67,000	—	—
Steel, hard	7·818	488·6	103,000	—	42,000,000
„ soft	7·834	489·6	121,700	—	29,000,000
Tin, cast	7·291	455·7	4,600	14,600	16,000,000
Type metal	10·450	653·1	—	—	—
Zinc, cast	7·028	439·3	8,500	—	13,[illegible]00,000
„ sheet	7·291	455·7	7,111	—	12,650,000

TIMBER.

SPECIFIC GRAVITY AND DENSITY.

Name.	Spec. Grav.	Lb. per cu. ft.	Name.	Spec. Grav.	Lb. per cu. ft.	Name.	Spec. Grav.
Acacia . . .	·71	44	Greenheart	1·00	62	Mahogany, Mexican .	·68
Alder . . .	·56	35	Hawthorn .	·91	57	Oak, English	·82
Apple . . .	·79	50	Hazel . . .	·86	54	Oak, Russian	·84
Ash English .	·74	46	Hornbeam .	·76	47	Oak, Spanish	1·04
Ash, American	·48	30	Jarrah . .	1·01	63	Oak, White (U.S.) . .	·98
Beech . . .	·70	44	Kauri, New Zealand .	·54	34	Pine, Red .	·55
Birch . . .	·75	47	Laburnum .	·92	57	Pine, Yellow	·50
Box	1·00	62	Larch, Russian .	·65	41	Pine, Oregon	·60
Cedar . . .	·49	31	Lancewood .	·68	42	Pine, Pitch .	·66
Chestnut . .	·54	33	Lignum-vitae	1·25	78	Sabicu . .	·92
Cypress . .	·66	41	Lime . . .	·76	47	Teak . . .	·80
Ebony . . .	1·20	75	Mahogany, Cuba . .	·77	48	Walnut . .	·67
Elder . . .	·70	43	Mahogany, Honduras .	·66	41	Willow . .	·40
Elm, English .	·56	35				Yew . . .	·81
Elm, Canada .	·75	47					
Fir, Riga . .	·56	35					
Fir, Spruce .	·48	30					

STRENGTH AND ELASTICITY.

Extracted from Laslett's "Timber and Timber Trees".

Name.	Tons per Square Inch. Tensile Strength.	Crushing Strength.	Bending Strength.	Modulus of Elasticity.	Name.	Tons per Square In[ch.] Tensile Strength.	Crushing Strength.	Bending Strength.
Ash, English .	1·7	3·1	5·2	640	Mahogany, Honduras .	1·3	2·7	5·2
Ash, American	2·4	2·4	3·8	390	Mahogany, Mexican . .	1·5	2·6	4·7
Cedar	1·3	2·0	—	—	Oak, English .	3·4	3·4	4·3
Elm, English .	2·4	2·5	2·4	280	Oak, Russian .	1·9	3·4	2·9
Elm, Canada .	4·1	4·0	5·5	700	Oak, Spanish .	—	—	3·4
Fir, Riga . .	1·6	3·0	4·5	750	Oak, White .	3·1	3·1	4·9
Fir, Spruce .	1·7	2·2	4·0	870	Pine, Red . .	1·2	2·1	3·9
Greenheart .	3·9	6·8	8·0	490	Pine, Yellow .	·9	varia	ble 3·[?]
Hornbeam . .	2·9	3·7	—	—	Pine, Pitch .	2·1	2·9	5·3
Jarrah . . .	1·3	3·2	4·2	330	Sabicu . . .	2·4	3·9	7·8
Kauri	2·0	2·8	—	—	Teak	1·5	2·8	5·3
Larch . . .	1·9	2·7	3·8	730				
Mahogany, Cuba . . .	1·7	3·2	5·2	850				

Note.—The bending strength and modulus of elasticity of woods are dete[rmined fro]m the bending tests, using the usual formulae. All these data are liable t[o va]riation.

Table of the Weight and Strength of Materials (concluded).

Miscellaneous Substances.

Name	Specific Gravity	Weight of a Cub. Foot, Lbs.	Crushing Force. Lbs. on Sq. In.	Name	Specific Gravity	Weight of a Cub. Foot, Lbs.	Crushing Force. Lbs. on Sq. In.
Asphalte . . .	2·50	156	—	Mica . . .	2·79	173	—
Asbestos . . .	3·07	191	—	Mortar . . .	2·48	155	—
Basalt . . .	2·72	170	16,800	Peat, hard . .	1·33	83	—
Brick, common .	2·00	125	—	Plumbago . .	2·27	139	—
„ red . .	2·16	134	808	Porcelain, China .	2·38	149	—
„ Welsh fire .	2·40	150	—	Portland stone .	2·57	161	6,856
Cement, Portland .	1·35	84	5,984	Pumice stone . .	·914	57	—
Clay . . .	1·93	120	—	Purbeck stone .	2·60	163	9,160
Coal . . .	1·27	79·4	—	Rag stone . .	2·47	154	—
Concrete . . .	2·00	124	—	Rotten stone . .	1·98	124	—
Cork . . .	·25	15	—	Salt	2·13	133	—
Glass, flint . .	3·078	192	27,500	Sand, fine pit . .	1·52	95	—
„ crown . .	2·52	157	31,000	„ coarse pit .	1·61	100	—
„ common green	2·528	158	31,876	„ river . .	1·88	117	—
„ plate . .	2·76	172	—	Slate . . .	2·62	164	15,000
Gypsum . . .	2·17	135	—	Sugar . . .	1·61	100	—
Granite . . .	2·70	169	12,800	Sulphate of soda .	2·20	137	—
Grindstone . .	2·14	134	—	Sulphur, native .	2·03	127	—
India rubber . .	·934	58·4	—	„ fused .	1·99	124	—
Lime, quick . .	·843	53	—	Tallow . . .	·94	59	—
Limestone . .	2·95	184	9,160	Tar	1·02	63	—
Marble . . .	2·72	170	9,219	Tile, common . .	1·83	113	—

Liquids.

Name	Specific Gravity	Weight of a Cub. Foot, Lbs.	Weight of a Cubic Inch, Ozs.	Name	Specific Gravity	Weight of a Cub. Foot, Lbs.	Weight of a Cubic Inch, Ozs.
Acetic acid . .	1·06	66·4	·615	Oil of olives . .	·915	57·2	·530
Alcohol, proof . .	·923	57·6	·534	„ turpentine .	·870	54·9	·508
Ether, acetic . .	·866	54	·501	„ whale . .	·923	57·7	·534
„ muriatic .	·730	45·6	·422	Oils, average . .	·880	55·0	·510
„ sulphuric .	·740	46·3	·428	Petroleum . .	·878	54·8	·508
Muriatic acid . .	1·20	75	·694	Sulphuric acid .	1·84	115	1·066
Nitric acid . .	1·27	79 4	·736	Vinegar . . .	1·01	63·1	·585
Oil of aniseed . .	·987	61·6	·570	Water, rain . .	1·00	62·5	·579
„ caraway seed	·905	56·6	·524	„ sea . .	1·025	64·0	·593
„ hempseed .	·926	57·8	·536	Wine, champagne .	·998	62·4	·578
„ lavender .	·894	55·9	·517	„ burgundy .	·991	62·0	·573
„ linseed . .	·940	58 8	·544	„ madeira .	1·04	65·0	·601
„ rapeseed .	·913	57·0	·528	„ port . .	·997	62·3	·577

Proof spirit has a specific gravity of $\frac{12}{13}$ or ·923. Spirit is said to be x per cent over proof when 100 parts of spirit yield on dilution $100+x$ parts of proof spirit; it is x per cent under proof when 100 parts contain $100-x$ parts of proof spirit and x parts of water.

ADMIRALTY TESTS, ETC., FOR MATERIALS.

General.

All galvanizing to be done by the 'hot process', unless otherwise specified, and tests should generally be carried out before galvanizing. The specified weight of plates, etc., shall be that before galvanizing.

All steel is to be free from lamination, surface and other defects. It is to be made by the open-hearth process, either acid or basic.

Hull material, whatever thickness, which is to be used for purposes where no structural strength is involved, need not be tensile tested, and only such bending and other usage tests as are considered necessary need be made.

Steel castings are to be clean, sound, out of twist, and as free as possible from blowholes; steel forgings are to be perfectly sound, clean, and free from all flaws. Where required, all castings and forgings must admit of being machined to the required dimensions; and no piecing, patching, bushing, stopping, or lining will be generally permitted.

No cast iron to be used except such as is permitted by specification, or as may be specially allowed.

All important shackles, links, etc., are generally to be made of Admiralty quality cable iron, and the iron is to be tested as specified for cable iron. The securities for receiving the clenches of the cables, all shackles, ring and eyebolts, stopper bolts and slips, all blocks, including eyes, eyeplates, or hooks for cables, boats' davits, and similar work, on the efficiency of which the safety of the vessel or of life directly depends, are to be tested by stress and fire-proved.

Davits of all kinds are to be bent hot and fire-proved in the presence of the overseer after bending, and tested when in place with a dead load equal to twice the estimated working load. Heel sockets, clamps, collars, lugs, and other work to be tested by the dead load tests in the davits, the forged parts being previously fire-proved as may be considered necessary.

Derricks to be tested with a dead load equal to twice the working load. The test load to be stamped on the derrick.

The above regulations apply to cable clenches, eyebolts, stopper bolts, and eyeplates for cable gear, as well as to davit and derrick fittings.

Instructions for Treatment of Mild and High Tensile Steel.

All plates or bars which can be bent *cold* are to be so treated; and if the whole length cannot be bent cold, the portion to be bent hot must be of a uniform temperature throughout; the varying temperature from hot to cold portion to be extended so as to avoid an abrupt termination of the heat.

In cases where plates or bars have to be heated, the greatest care should be taken to prevent any work being done upon the material after it has fallen to the dangerous limit of temperature known as a "blue-heat"—say from 600° to 400° F. Should this limit be reached during working, the plates or bars should be re-heated.

Where plates or bars have been heated throughout for bending, flanging, etc., and the work has been completed at one heat, subsequent annealing is unnecessary, but care should be taken to prevent, as far as possible any sudden cooling of the material.

Special Quality steel plates H.T. should not be heated in any way after delivery at the shipyard.

Special Quality steel plates H.T. are to be planed ⅛ in. on the edges and butts before curving, bending, or working.

Where simple forge-work has been done, such as the formation of joggles, corners, and easy curves or bends, on portions of plates or bars, and the material has not been much distressed, subsequent annealing is unnecessary.

Plates or bars which have had a large amount of work put upon them while hot, and have to be re-heated, should be subsequently annealed. It is preferred that this annealing should be done simultaneously over the whole of each plate or bar when this can be done conveniently. If it is inconvenient to perform the operation of annealing at one time for the whole of a plate or bar, proportions may be annealed separately, proper care being taken to prevent an abrupt termination of the line of heat. If the severe working has been limited to a comparatively small part of a plate or bar annealing may be limited to the parts which have been heated, the same care being taken to prevent an abrupt termination of the line of heat.

If desired, exceptionally long or quickly curved bars, such as frames, may be formed of shorter pieces with the butts suitable shifted and strapped.

It is not necessary generally to anneal plates or bars after punching as a means of making good damage done in punching. For plating that forms an important feature in the general structural strength, such as the inner and outer bottom plating, deck plating, deck stringers, plating behind side armour, etc., the butt straps should have the holes drilled or be annealed after the holes are punched. In such plating

the countersunk holes should be punched about ⅛ in. less in diameter than the rivets which are used, the enlargement of the holes being made in the countersinking, which should in all cases be carried through the whole thickness of the plates. All countersinking is to be carefully done.

It is important that the whole surface of the bottom plating should be thoroughly cleared of the scale formed in manufacture before any paint or composition is put upon it.

Tensile Test Pieces.

Tensile test pieces are of one of three types: A for flat and B and Z for circular pieces of material. The actual diameters of test pieces of the forms B and Z should be as approved by the overseer.

Test Piece A.—To be of rectangular section, planed down to the width specified below over a length of at least 9 inches. Gauge marks to be 8 inches apart.

For test pieces over ⅞″ thick, maximum width allowed .	=	1½″
,, ,, ⅜″ to ⅞″ inclusive, maximum width allowed	=	2″
,, ,, under ⅜″ maximum width allowed . .	=	2½″

Note.—All test pieces may be cut in a planing machine and have the sharp edges taken off.

Test Piece B.—To be of circular section with enlarged ends. To be parallel for a length of not less than nine times the reduced diameter. Gauge length not less than eight times the diameter.

Test Piece Z.—To be of circular section with enlarged ends. To be parallel for a length of not less than four and a half times the reduced diameter. Gauge length not less than four times the diameter.

Ship Plates, Ordinary Quality.

The plates will be ordered by weight per superficial foot. The weights named must be adhered to as nearly as possible for each plate, but the latitude stated below will be permitted.

Plates 20 lb. per square foot and upwards.	5 per cent below the specified weight. None above.
Plates under 20 lb. per square foot.	From 5 per cent below to 5 per cent above the specified weight.

Strips 1½ inches wide, cut crosswise or lengthwise, must stand without cracking bending double in a press, or hammering double over a block, to a curve of which the inner radius is not greater than one and a half times the thickness

of the steel tested. The strips to be tested as the overseer may wish, either cold from the plate, or after being heated uniformly to a blood red, and cooled in water of about 80° F. The thickness of strips cut for bending tests to be equal to the thickness of the plate, except that they need not be more than ¾ in. thick in the case of plates of over 30 lb., in which case the strips are to be so bent that an original outside surface is always in tension.

Strips must also stand such hot forge tests as necessary to show that the plates will stand such heat treatment and bending as they may be subjected to in the shipyard.

The pieces of plate cut out for tensile testing are to be in accordance with test piece A when cut either lengthwise or crosswise, they are to have an ultimate tensile strength of not less than 26, and not more than 30, tons per square inch of section, with an elongation of not less than 20 per cent on a length of 8 inches. (Test piece A.) For plates of 10 lb. and under the elongation may be not less than 18 per cent.

Special Quality Steel Plates, H.T.

The Specification for these plates, including the general working qualities, is exactly the same as for ordinary quality plates, except as follows:—

Each special quality plate is to be stamped H.T.; and the ultimate tensile strength is to be not less than 33 tons and not more than 38 tons per square inch.

Bending Tests.—Test pieces 1½ inches wide to bend cold without cracking through an angle of 180°, the inner radius of bend being not greater than twice the thickness of plate tested.

No sample must, on analysis, show more than 0·15 per cent of silicon for plates up to and including 40 lb. per square foot, nor more than 0·2 per cent for plates over 40 lb. per square foot. It is particularly desired that this steel should contain not less than 0·1 and not more than 0·15 per cent of silicon, and not less than 0·25 and not more than 0·35 per cent of carbon for plates up to and including 40 lb. per square foot; and the same percentage of carbon with a slightly higher percentage of silicon for plates over 40 lb. per square foot.

Special Quality Steel, H.H.T. (Destroyer Quality).

All plates and sheets shall be carefully annealed in a proper annealing furnace after rolling and before test pieces are taken. The test pieces shall be taken before galvanizing.

(*a*) *Tensile Test.*—Plates and sheets of 3½ lb. per square foot and upwards are to have an ultimate tensile strength of

37 to 43 tons per square inch, and sheets under $8\frac{1}{2}$ lb. per square foot are to have an ultimate tensile strength of from 35 to 45 tons per square inch, with an elastic limit of not less than one half the ultimate tensile strength, with a minimum of 20 tons.

This material is to have a minimum elongation on a length of 8 inches (test piece A) of—

> 15 per cent for plates 10 lb. and above; 15 per cent for sheets $7\frac{1}{2}$ lb. up to, but not including 10 lb.; 14 per cent for 5 lb. up to, but not including $7\frac{1}{2}$ lb., and 12 per cent for less than 5 lb. per square foot.

(*b*) *Bending Test.*—Test pieces to bend cold without cracking through an angle of 180°, the inner radius of bend being not greater than twice the thickness of the plate tested.

Each plate or sheet is to be marked with the letters H.H.T. The general conditions to be as for ordinary quality steel plates, except that the weight is subject to a latitude of 10 per cent above the weight specified, but nothing below.

Nickel Steel Ship Plates.

The specification for these plates is the same as for ordinary quality plates, except as follows:—

> Each nickel steel plate is to be stamped N.I. The steel must contain not less than 3 per cent of nickel, and is to be such that it can be sheared, punched, bent, etc., with ordinary shipyard appliances. The ultimate tensile strength is to be not less than 36 tons and not more than 40 tons per square inch, with an elongation of not less than 18 per cent on a length of 8 inches (test piece A). The special forge test on strips is not required for this class of plate.

Chequered Steel Plates.

To be of diamond pattern, measuring in the clear $1\frac{3}{4}'' \times \frac{7}{8}''$ along the diagonals between the ridges, which should be $\frac{3}{32}''$ wide, and project from $\frac{5}{64}''$ to $\frac{7}{64}''$ above the upper surface of plate.

For plates demanded of rectangular form the edges are to be sheared parallel to the diagonals.

The plates will be ordered by weight per superficial foot, which weight is always to be taken as inclusive of the rib, but exclusive of the galvanizing when galvanizing is ordered. The weights named must be adhered to as nearly as practicable with the same latitude as with ship plates.

A strip, sheared or cut lengthwise or crosswise from the plate and not less than $1\frac{1}{2}$ inches wide, must stand without fracture being doubled over when cold until the internal radius of bend is not greater than $1\frac{1}{2}$ times the thickness of the test piece and the sides are parallel.

The pieces of plate cut out for tensile testing are to be in accordance with test piece A. Either lengthwise or crosswise they are to have an ultimate tensile strength of not less than 26 and not more than 30 tons per square inch, with a minimum elongation of 20 per cent on a length of 8 inches for plates above $12\frac{1}{2}$ lb. per square foot, and 16 per cent for plates $12\frac{1}{2}$ lb. per square foot and below.

Mild Steel for Angles, Bulbs, etc.

Strips cut $1\frac{1}{2}$ inches wide, or pieces of full section of the bar as rolled, must stand bending double in a press, or hammering double over a block to a curve, of which the inner radius is not greater than $1\frac{1}{2}$ times the thickness of the steel tested. The samples to be tested either cold from the bar, or after being heated uniformly to a blood red, and cooled in water of about 80° F. The steel is to stand such forge tests, both hot and cold, as may be sufficient, to prove soundness of material and fitness for the service.

The pieces of beam, angle, etc., cut out for tensile testing are to have an ultimate tensile strength of not less than 26 and not more than 30 tons per square inch of section, with an elongation of not less than 20 per cent on a length of 8 inches (test piece A) or full section of the bar as rolled.

Sectional material will be ordered by weight per foot run; a latitude of 5 per cent below these weights, but nothing above, being allowed for rolling.

Mild Steel Bars (Flat, Round, Segmental, Square, and Hexagonal).

Test pieces from the bars are to have an ultimate tensile strength of not less than 28 tons per square inch, and not more than 32 tons per square inch, with an elongation of not less than 20 per cent measured on test pieces A or B, or 23 per cent on test piece Z.

Strip cut not less than 1 in. square, or pieces of the full thickness or sections of the bar as rolled, must stand bending double in a press or hammering double over a block to a curve of which the inner radius is not greater than $1\frac{1}{2}$ times the thickness of the steel tested. The samples tested are to be bent with the rolled or outside surface in tension; either cold from the bar, or after being heated uniformly to a blood red and cooled in water of about 80° F.

The steel is to stand such forge tests, both hot and cold, as may be sufficient to prove soundness of material and fitness for the service.

Steel Rivets.

Ordinary Quality.—The whole of the rivets are to be properly heated in making, except that rivets not greater than $\frac{7}{16}$ of an inch in diameter may be made cold. Care is to

be taken that the cold made rivets are properly annealed, and those made hot are to be allowed to cool gradually.

The tensile breaking strength of samples selected from mild steel rivet bars when ready for rivet making shall be not less than 26 and not more than 30 tons per square inch of section, with an elongation of not less than 25 per cent on 8 diameters of the test piece. (Test piece B.) The bars may be tested the full size as rolled.

Rivets are to stand the following tests :—

(*a*) Bending the shanks cold and hammering until the two parts of the shank touch, in the manner shown in fig. 159, without fracture on the outside of the bend.

(*b*) Flattening of the rivet head, while hot, in the manner shown in fig. 160, without cracking at the edges. The head to be flattened until its diameter is not less than 2½ times the diameter of the shank.

Fig. 159.

Fig. 160.

Certain of the finished rivets may be subjected to a tensile test, and of the screwed rivets to a cold bending test after the screw is cut.

Special Quality, H.T. and H.H.T.—Rivets for use in high tensile steel plates are to be made of steel of special quality and are subject to the same conditions and tests as ordinary quality rivets except as under :—

(A) *H.T.*, 3 *Rib.*—The tensile strength of the bars up to and including ¾ in. in diameter is to be not less than 32 tons and not more than 38 tons per square inch, with an elongation of not less than 20 per cent on a length of eight diameters (test piece B). For bars over ¾ in. in diameter the tensile strength shall not be less than 32 tons and not more than 36 tons per square inch, with an elongation of 20 per cent (test piece B). Each pan-head and snap-head rivet shall be marked in the usual manner for such rivets with three equidistant ribs on the side of the head; countersunk rivets shall be marked with a triangular pyramidal recess. No chemical analysis is required for these rivet bars.

(B) *H.H.T.*, 4 *Rib.*—The tensile strength of the bars is to be not less than 37 tons and not more than 43 tons per square inch, with an elongation of not less than 18 per cent on a length of eight diameters (test piece B). For bars less than ½ in. diameter a minimum elongation of 25 per cent on four diameters (test piece Z) will be accepted in lieu. Each pan-head and snap-head rivet shall be marked with four

equidistant ribs on the side of the head; countersunk rivets shall be marked with a rectangular pyramidal recess.

Nickel Steel Rivets.—To be subject to the same general conditions and tests as for ordinary rivets, except that the tensile strength of the bars to be not less than 36 tons and not more than 40 tons per square inch, with an elongation of not less than 20 per cent on a length of eight diameters. (Test piece B.)

The rivets to be branded with a single rib on the side of the head. To contain not less than 3 per cent of nickel and to admit of being worked in the shipyard like ordinary steel rivets.

Steel Bolts, Nuts and Studs.—The bolt heads shall be forged from the solid and the nuts shall be made from the solid bar, except in cases where bolts, studs and nuts are manufactured by machinery from drawn bars; the bars in the latter case are to be carefully annealed beforehand.

Test pieces for bars over 1 in. in diameter to be 1 in. in diameter, and for bars under 1 in. diameter to be the full section of the bar. To have an ultimate tensile strength of not less than 30 tons per square inch and not more than 35 tons per square inch, with an elongation of not less than 23 per cent measured on test piece B. Pieces from the selected bars shall be capable of being bent cold without fracture through an angle of 180°, the internal radius of bend being not greater than 1½ times the thickness or diameter of the bar; or after being heated uniformly to a blood red and cooled in water of about 80° F., must stand bending double without fracture in a press, to a curve of which the inner radius is not greater than 1½ times the thickness or diameter.

The tests to which the bolts and studs will be subjected are as follows:—

(*a*) Nicking on one side and bending to show the quality of the material, which must be satisfactory to the overseer.

(*b*) When the bolts and studs are of sufficient length in the plain part to admit of being bent cold they shall stand bending double without fracture in a press to a curve of which the inner radius is not greater than 1½ times the diameter of the bolt or stud.

When the bolts and studs are not of sufficient length in the plain part to admit of being bent cold the screwed part shall stand bending cold without fracture, as follows:—

½ in diameter and under ...	through an angle of		35°
Above ½ in. and under 1 in.	„	„	30°
1 in. diameter and above ...	„	„	25°

Samples of the nuts must stand such drift tests as may be considered necessary.

Steel Forgings.

The ingot steel for forgings is to be made by the acid open-hearth process.

The forgings are to be gradually and uniformly forged from solid ingots, from which at least 40 per cent of the total weight of the ingot is to be removed from the top end and at least 5 per cent of the total weight of the ingot from the bottom end. These ends of the ingot may be removed either before or on the completion of the forging, and are not to be used for any forgings for H.M. Service.

When finished the sectional area of any part of a steel forging (as forged) shall generally not exceed one-sixth of the mean sectional area of the original ingot used for the forging, and no part of the forging (as forged) shall exceed one-half of the mean sectional area of the original ingot used for the forging. The finished forging must be perfectly sound.

All steel forgings shall be thoroughly annealed in a properly constructed annealing furnace, which must permit of the whole forging being uniformly raised in temperature throughout its whole extent to the necessary intensity required for annealing purposes. If the forging be subsequently heated for any further forging it shall again be similarly annealed if required.

Tests.—The tensile strength and ductility shall be determined from test pieces prepared from sample test pieces cut lengthwise from the finished forging from a part of not less sectional dimensions than the body of the forging. Such test pieces shall be machined from the sample piece without forging down, and the sample piece shall not be detached from the forging until the annealing of such forging has been completed.

One tensile and one bend test are to be taken from each forging, and they are to be cut from any part of the sample piece as nearly as practicable midway between the centre and outer edges, and are to be tested as follows :—

Tensile Test.—Test pieces prepared in accordance with test piece Z are to satisfy the following conditions :—

Quality.	Ultimate Tensile Strength per square inch of section.		Elongation.
	Not more than	Not less than	
A.	38 tons	34 tons.	The elongation measured on the test piece must not be less than 19 per cent for 38 ton steel, and not less than 29 per cent for 28 ton steel, and in no case must the sum of the tensile breaking strength and corresponding elongation be less than 57.
B.	35 tons.	31 tons.	
C.	32 tons	28 tons.	

Cold Bend Tests.—The cold bend tests are to be made upon test pieces of rectangular section 1 in. wide and $\frac{3}{4}$ in. thick. The test pieces are to be machined to these dimensions and the edges rounded to a radius of $\frac{1}{16}$ in. The test pieces shall be bent over the thinner section.

The test pieces are to be bent by pressure or by blows, and must withstand without fracture being bent through an angle of 180°, the internal radius of the bend being not greater than that specified below.

Specified Tensile Strength of Forging.	Internal Radius of Test Piece after Bending.
28 to 32 tons per square inch . .	$\frac{1}{4}$ inch.
Above 32 and up to 36 tons per square inch	$\frac{3}{8}$ inch.
Above 36 and up to 38 tons per square inch	$\frac{5}{8}$ inch.

Forgings, after completion, are to be subjected to the usual fire-proving tests, if considered necessary.

Special Quality Steel for Sheave Pins, etc.

The bars to be forged or rolled from ingots of acid open-hearth or crucible steel.

The material to stand the following tests after all heat treatment, if any, has been carried out on the material for the purpose of converting it into pins or otherwise.

Ultimate tensile strength . .	40 to 50 tons per square inch.
Elongation on a length of 4 diameters (test piece Z). .	Not less than 15 per cent.
Bend test, cold	Through 90° without fracture, the internal radius of the bend being not greater than the diameter of the test piece.

Steel Castings.

Steel castings for purpose of ship construction are divided into three classes, viz. 'Quality A', 'Quality B', and 'Quality C', in accordance with the following classification:—

Quality A.—Boss castings, if forming part of structure of ship, and stern tubes, capstan gear, cut up of keel, deck compressors (where formed of castings), head and heels for derricks, riding bitts, rudder frames, rudder head castings, rudder crossheads, shaft brackets, stems, sternposts and stern castings, steering gear fittings, bracket on mast to take heel of derrick.

Quality B.—Sheaves to blocks for derricks, coaling scuttles in protective decks, bearing rings, boss castings, bollards, cleats, deck pipes, fairleads, hawse pipes, link plates for securing guns, net defence—roller fairleads, boom heel sockets, packing rings, frames for watertight doors, watertight scuttles, stern mooring pipes, beds to coaling winches, shoes for davits, brackets for helm signal gear.

*Quality C.—Articles except those marked * may be made in special malleable cast iron in lieu of quality C.* Brackets, etc., for valve gearing,* brackets, etc., for watertight doors,* dismounting gear, mitre wheels and spur wheels for work other than steering or capstan gear, mud boxes, scuttles, coaling, hand up and side, scuppers, universal joints,* hand wheels, weed boxes, hawser reel castings, link plates for net defence.*

All castings to be clean and free from defect, and to be annealed. Quality A to be of open-hearth steel, either acid or basic.

Tests, etc., for Quality A Castings.—(*a*) Pieces of suitable section and length to be formed on each casting for providing test pieces, or test pieces may be cut from the head of the casting. Where a number of castings are made from one charge, test pieces to be provided as required.

(*b*) One piece to be turned in accordance with test piece Z, and to have a minimum tensile strength of 26 tons per square inch. The elongation to be at least 13½ per cent on a length of 4 diameters.

(*c*) A second piece to be planed to a section 1 inch square, and to admit of being bent cold without fracture in a press, or on a slab or block through an angle of 45°, or if preferred turned 1 inch diameter and bent through an angle of not less than 60°, the internal radius of bend being not greater than 1 inch in either case.

(*d*) Additional pieces to be available for repeating either of the above tests, in case of any dispute or doubt as to the result representing the quality of the material of the casting.

(*e*) Each casting to be raised to an angle or height chosen by the overseer and allowed to fall on hard ground of the hardness of a good macadamised road, or on an iron or steel plate, the casting to show no signs of fracture after this test.

After the above tests, each casting is to be subjected to such hammering tests as may be considered necessary to prove the soundness and efficiency of the casting for the intended service, and carefully examined for any surface defects or flaws.

Tests, etc., for Quality B Castings.—To receive the same tests as A quality castings, except that in (*b*) the elongation to be at least 10 per cent on a length of 4 diameters.

Tests, etc., for Quality C Castings.—(*a*) Each casting to be raised to a height named by the overseer, and allowed

to fall on hard ground of the hardness of a good macadamized road, or an iron or steel plate; the casting to show no signs of fracture after this test.

(*b*) After the above test, each casting to be subjected to such hammering tests as may be considered necessary to prove the soundness and efficiency of the casting for the intended service, and carefully examined for any surface defects or flaws.

Certain of the articles may be selected and tested to destruction with a view to ascertaining the efficiency of the casting.

Note applying to all Grades of Castings.—In exceptional cases, such as in castings of light section, large area, and intricate form, the drop test may be waived.

Steel Tubes for Magazine Coolers, Pillars, etc.

The ends of the tubes must admit of being expanded hot, without injury, to an increase of $\frac{1}{20}$ the diameter of the tube. Strips cut from the tubes or pieces of full section of the tubes must have a tensile strength not less than 24 tons and not exceeding 30 tons per square inch, with an elongation of at least 33 per cent in a length of 2 inches. They must also be capable of being bent without fracture through an angle of 180°, the internal radius of bend being not greater than $\frac{1}{2}$ in.; the strips to be tested either cold or after being heated to a blood red and cooled in water of about 80° F. The tubes for magazine coolers shall stand an hydraulic pressure of 100 lb. per square inch, without leakage.

The rolled material from which the flanges are made shall be of the same quality as the tubes, as specified above.

Wrought Iron Forgings.

Iron forgings are to be made of the best selected scrap iron, of approved quality, forged into blooms. Jump welds are to be entirely avoided for important welds.

Samples cut from the forgings are to be tested as follows:—

The strength and ductility shall be determined from test pieces which are to be prepared from sample pieces cut lengthwise from the forging from a part of not less sectional dimensions than the body of the forging. Such test pieces shall be machined from the sample pieces without being forged down.

Tensile Test.—A test piece prepared in accordance with test piece B is to have a tensile strength of not less than 22 tons per square inch of section, with an elongation of not less than 22 per cent on a length of 8 diameters of the test piece.

Bend Test.—A test piece 1 inch square must withstand without fracture being bent cold through an angle of 180°,

the internal radius of the bend being not greater than 1½ times the thickness of the test piece. A sample is to be notched and bent cold to ascertain the quality of the material.

At least one tensile and one cold bend test are to be taken from each forging.

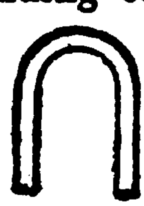
Cable Iron.

The iron is to be of good welding quality, free from lamination. Special consideration is to be given to obtaining a good fibre in the iron.

The samples of every description of iron shall have an ultimate tensile strength respectively :—

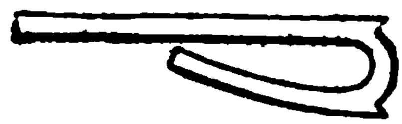
Of not less than 23 tons to the square inch of section, for sizes under 2¼ inches in diameter ; of not less than 22½ tons to the square inch of section, for sizes from 2¼ to 2$\frac{9}{16}$ inches in diameter, both sizes inclusive ; and of not less than 22 tons to the square inch of section, for sizes above 2$\frac{9}{16}$ inches in diameter.

Bars less than 1 inch diameter are to be tested on the 8 diameter test piece (B), either full-sized as rolled, or turned down, the reduced portion to be not less than ½ in. diameter ; and the elongation is to be not less than 22 per cent on a length of 8 diameters. Bars 1 inch diameter and over may be tested full size as rolled, or turned down, the reduced portion to be not less than 1 inch diameter, and the elongation may be measured on a gauge length of four times the diameter of the test piece (test piece Z), in which case the elongation is to be not less than 26 per cent ; or may be measured on a gauge length of 8 diameters (test piece B), in which case the elongation is to be not less than 22 per cent.

Forge Test, Cold.—Bars of 1 inch diameter and above are to admit of bending cold, when practicable, through an angle of 180°, thus,  and bars under 1 inch shall admit of bending cold, thus,  in each case to the same radius as the end of the link for which they are generally used.

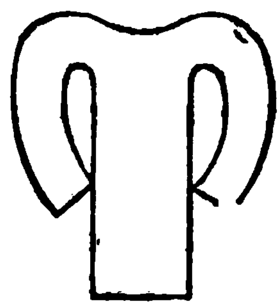
In the case of the larger sizes where this is not practicable, the bars may be cut longitudinally through the centre. Each portion to admit of bending cold without fracture with the outside original surface in tension through an angle of 180°, the inner radius of bend being not greater than 1½ times the thickness of the test piece.

A sample is to be notched and bent, thus,



to show the fibre and quality of the iron.

Forge Test, Hot.—Bars are to be punched with a punch one-third the diameter of the bar, at a distance of $1\frac{1}{2}$ diameters from the end of the bar. The hole is then to be drifted out to $1\frac{1}{2}$ times the diameter of the bar, the side of the hole split, and the ends must then admit of turning back without fracture, thus—



Cast Iron.

The minimum tensile strength to be 9 tons per square inch taken on a length of not less than 4 diameters (test piece Z). The transverse breaking load for a bar of 1 inch square, loaded at the middle between supports 1 foot apart, is not to be less than 2,000 lbs.

Special Malleable Iron Castings.—Each casting to be sound, clean and free from blow-holes, and to be well annealed. To stand being dropped, without sign of injury, from a height of from 9 to 15 feet on to an iron or steel slab of not less than $1\frac{1}{2}$ inches in thickness. The casting to be afterwards subjected to such hammering tests as may be necessary to prove the soundness and efficiency of the casting for the intended service.

Two test pieces are to be provided from each cast, each having a parallel section of $1'' \times \frac{3}{8}''$ for a length of at least $3\frac{3}{8}''$ with ends to suit the mode of grip employed.

One of these test pieces is to have a tensile strength of not less than 18 tons per square inch, with an elongation of not less than $4\frac{1}{2}$ per cent on a length of 3 inches. The other test piece is to stand bending cold in the direction of the lesser thickness without sign of injury through an angle of 90°, the internal radius of bend being not greater than 1 inch.

Certain of the articles may be tested to destruction with the view of ascertaining the fitness of the castings for the service intended.

Ordinary Malleable Cast Iron.—Castings shall stand being dropped on a slab of cast iron, or one of equivalent hardness, from a height of 10 to 20 feet. Strips cut from the castings are to stand being bent cold without fracture through an angle of 45°, the internal radius of bend being not greater than the thickness of the piece tested. Pieces from the castings may be broken to show the extent of annealing.

Naval Brass.

Naval brass is to be of the following composition: best new selected copper 62 per cent, tin at least 1 per cent, the remainder zinc. In no case will Naval brass be accepted having less than 61 per cent copper. The impurities shall not exceed $\frac{3}{4}$ of 1 per cent.

All Naval brass articles are to have good, clean, and smooth surfaces, free from black oxide, blisters, and internal sponginess, and are to be hard-rolled cold. Naval brass rods may be extruded as may be approved. The bars are to be tested without annealing, and the test pieces are not to be annealed.

Bars.—(1) All Naval brass bars are to be cleaned and straightened. (2) They are to be capable of being hammered, hot, to a fine point. (3) They must stand being bent, cold, without fracture through an angle of 75° as follows: The test piece will be placed on two supports 10 inches apart and forced down in the centre by a die, which has a radius equal to the diameter tested. For bars over $1\frac{1}{2}$ inches in diameter or thickness, this test is to be carried out on a piece of $1\frac{1}{2}$ inches in diameter or thickness, selected from the outside portion of bar, and bent so that the original outside surface is in tension. In bars not of circular section, the corners may be well rounded off before the bending test. (4) A sufficient number of bars are to be nicked at the ends and broken so as to satisfy the Inspecting Officers as to their general soundness. (5) They must stand the following tensile tests, which are to be taken from the same bar as bending tests: Round and hexagonal bars $\frac{3}{4}$ in. diameter and under are to have an ultimate tensile strength of not less than 26 tons per square inch. Elongation to be not less than 20 per cent in 2 inches. Round and hexagonal bars above $\frac{3}{4}$ in. diameter are to have an ultimate tensile strength of not less than 22 tons per square inch, whether turned down in the middle or not. Elongation to be not less than 20 per cent in 2 inches. Bars of any other section are to have a tensile strength of not less than 22 tons per square inch, and for elongation are to be treated as round bars of corresponding sectional size.

Sheets.—All Naval brass sheets of $\frac{3}{8}$ in. thickness or less are, if ordered to be supplied annealed, to be capable of being doubled, cold, to a curve the inner radius of which is not greater than the thickness of sample without fracture, and

to stand a tensile stress of not less than 26 tons per square inch, with an elongation of not less than 30 per cent in 2 inches. Hard-rolled sheets are to stand without annealing a tensile strain of 26 tons per square inch, with an elongation of 25 per cent, and a bending test through an angle of 135°. The bending test may be carried out by bending up to a right angle in a suitable vice, and completed by mallet on a smooth anvil or other means.

Sheathing sheets are to be annealed and thoroughly cleaned after rolling, and to have a clean smooth surface free from buckling.

Plates, Tube, and Diaphragm above ⅜ in. in thickness.—Surfaces are to be flat, smooth from the rolls and free from scoring, laminations, pitting, or cracks. The billets are to be machined on both sides either immediately before or after "breaking down"; all defects to be "dressed out" before the rolling is proceeded with. Test pieces are not to be annealed.

Plates above ⅜ in. and up to ½ in. thick to stand bending through an angle of 135°, the internal radius of bend being not greater than the thickness of the plate, the bending test being carried out as described under brass sheets above. They are to stand a tensile stress of not less than 26 tons per square inch, with an elongation of not less than 20 per cent in 2 inches.

Plates above ½ in. and up to ¾ in. thick; the bending test angle is to be 120°. Tensile test to be 24 tons per square inch with an elongation of 20 per cent in 2 inches.

Plates above ¾ in. thick; the bending test angle is to be 90°. Tensile test to be 22 tons per square inch with an elongation of 20 per cent in 2 inches.

Naval brass sheets and plates must also satisfactorily pass a hot forging test.

Naval Brass Castings.—Test pieces turned, must have an ultimate tensile strength of not less than 10 tons per square inch, with an elongation of not less than 7½ per cent on a length of 4 diameters (test piece Z).

Gun-metal.

The gun-metal used in the manufacture of any article, except where specially approved, is to be of the following composition: copper not less than 86 per cent, tin 10 to 12 per cent, zinc 2 per cent maximum. The whole to be of good clean metal free from any admixture of lead.

Tensile Tests.—Pieces taken from the castings, prepared in accordance with test piece Z, are to have an ultimate tensile strength of not less than 14 tons per square inch, with an elongation of at least 7½ per cent on a length of 4 diameters.

PHOSPHOR BRONZE.

All phosphor bronze is to have the following composition: copper 83 per cent, tin 10 per cent, phosphide of copper 7 per cent. If preferred, the composition may be copper 90 per cent, phosphor tin 10, the latter to contain 5 per cent phosphorus.

Test pieces must have an ultimate tensile strength of 15 tons per square inch, with an elongation of at least 10 per cent in a length of 4 diameters (test piece Z), and on analysis to show not less than 0·3 per cent of phosphorus.

Should an especially hard material for bearings, etc., be desired, the composition of the phosphor bronze may be made, copper 85 per cent, phosphor tin 15 per cent, with a chemical analysis showing not less than 3 per cent of phosphorus. In this case the tensile strength must be 7½ tons per square inch, with an elongation of not less than 1 per cent on test piece Z.

ORDINARY BRASS.

All brass articles of minor importance such as label plates, buttons, hooks, etc., are to be of the composition best adapted to the uses for which they are severally intended, but no brass articles will be accepted which are found on analysis to contain more than 3½ per cent of lead.

COPPER.

Copper used in the manufacture of any copper articles is to assay not less than 99·3 per cent. The quality of the copper may be tested by the following Muntz metal test:—3 lb. of the copper will be placed in the melting-pot, covered with pieces of hard wood or charcoal, to prevent the loss of zinc when added. When the metal has melted 2 lb. of zinc will be added, and the mixture stirred and run into a cake about 4 inches square in an open iron mould. When the cake has set it will be allowed to cool gradually in air, and when cold it will be nicked with a cold chisel, and broken carefully to show the fracture. If the cake be tough and break with a fine silky fracture the quality is considered good, but if it break short with a coarse stringy fracture, and with a yellow colour, the quality is considered bad.

Copper Pipes.—Copper pipes are not to be made by the electric depositing process, and copper so made is not to be used for their manufacture unless it is remelted.

Strips cut longitudinally from pipes after annealing in water are to have an ultimate tensile strength of not less than 14 tons per square inch with an elongation in a length of 2 inches of not less than 35 per cent.

Strips cut longitudinally and transversely are to stand bending cold, double, the internal radius of bend being not greater than the thickness of a strip, if unannealed, and until the two sides meet, if annealed, and in the latter case to be hammered to a fine edge without cracking.

Each tube is to be tested internally by water pressure, without leakage or permanent increase of diameter.

No pipe is to be less at any part than the thickness ordered, nor should its weight exceed by more than $7\frac{1}{2}$ per cent that calculated to be due to its dimensions, taking 555 lb. per cubic foot.

Flanges of all copper pipes are to be of the following mixture: copper, 85 per cent; zinc, 15 per cent.

Copper Sheathing.—Copper sheathing includes sheets of 12, 16, 18, 28, and 32 oz. per square foot. The Muntz metal test, as specified above, is to be made on selected sheets. The sheets are to be hot rolled to about $\frac{5}{8}$ the finished length. To be hard rolled cold and afterwards annealed and cleaned. The oxide scale is to be completely removed before the cold rolling process and also after the final annealing. The finished sheets are to have bright, clean, and smooth surfaces perfectly free from black oxide or discoloration. The edges are to be neatly sheared and the sheets equal in softness and finish, and in all respects conformable to the pattern sheet. The nail holes to be marked in the 32 and 28 oz. sheets.

Copper Sheet.—Strips cut longitudinally from and portions of copper sheets are to have, after annealing in water, an ultimate tensile strength of not less than 14 tons per square inch, with an elongation of not less than 30 per cent in a length of 2 inches. Strips cut lengthways and crosswise are, if unannealed, to stand bending double, the internal radius of bend being not greater than the thickness of the strip. If annealed, the strips must stand bending until the two sides meet, and hammering to a fine edge without cracking.

Copper Bars.—All copper bars to be hard rolled, cleaned, and straightened. After annealing, to have an ultimate tensile strength of not less than 14 tons per square inch, with an elongation of not less than 30 per cent in a length of 2 inches. The bars are to be capable of being bent completely double without fracture, the internal radius of bend not being greater than the diameter or thickness of the bar. They are also to be capable of being hammered hot to a fine point.

LEAD.

Sheet lead is to stand, without injury, cutting or bossing up, or any other usage test that may be considered necessary.

Lead pipe is to stand, without bursting, a water pressure test of 300 lb. per square inch up to $1\frac{1}{2}$ inch diameter, and

200 lb. per square inch above $1\frac{1}{2}$ inches and up to 4 inches. The pipe is to have sufficient ductility to admit of turning or flanging at the ends to double the internal diameter without splitting.

ZINC.

The Zinc for Protectors, etc.—Zinc must not contain more than 1·1 per cent of lead.

WOOD.

All woodwork to be well seasoned and free from objectionable shakes, sap, defective knots, etc. Deck planks to be free from heartwood. All teak is to be East Indian.

INDIA-RUBBER

(other than that used exclusively for machinery purposes).

(*a*) The vulcanized india-rubber is to be of a homogeneous character throughout, as evidenced by microscopical examination, is to be thoroughly compressed, free from air-holes, pores, and all other imperfections, is not to contain any crumb rubber, recovered rubber, or other treated or waste rubber, or rubber substitute of any kind, and is to stand the tests mentioned below without its quality being impaired.

(*b*) The quality of the caoutchouc used for all vulcanized india-rubber goods described—subject to the exceptions named below—must be of such a character that after it has been made up into the vulcanized and finished article as defined above, not more than 10 parts per cent of organic matter and sulphur, calculated on the non-mineral matter present, can be extracted from the rubber by boiling it for six hours in a finely-ground condition with a 6 per cent solution of alcoholic caustic potash.

(*c*) Although maximum percentages of sulphur are named in the specification the quantities used should be as low as possible consistent with proper vulcanization.

(*d*) Where the use of pure best quality caoutchouc is prescribed it must be of such quality that not more than 6 parts per cent of the organic matter present can be extracted from the rubber by boiling it for six hours in a finely-divided condition with a 6 per cent solution of an alcoholic caustic potash.

Quality 8. *Vulcanized india-rubber sheet or valves, etc.*, for purposes requiring considerable elasticity, to be made of pure caoutchouc, of the quality specified at (*b*) above, and with no other ingredients than sulphur, the proportion of which is not to exceed 4 per cent reckoned on the manufactured rubber; is to endure a dry heat test of 270° F for two hours without impairing its quality.

Quality 8a. Vulcanized india-rubber sheets, valves, washers, or rings, etc., for side scuttles, electric light, and hose fitting, etc., to be made up of pure caoutchouc, of the quality specified at (*b*) above, and with no other ingredients than sulphur and white oxide of zinc; the sulphur is not to exceed 3 per cent, and the oxide of zinc is not to exceed 40 per cent, reckoned on the manufactured rubber; to endure dry heat test of 270° F for two hours without impairing its quality.

Quality 8b. Vulcanized india-rubber sheet or washers, etc., including *armour bolt washers*, to be made of the same ingredients as specified above for 8*a* quality rubber, except that the oxide of zinc is not to exceed 50 per cent, and the sulphur is not to exceed 2½ per cent.

Quality 8c. Vulcanized india-rubber sheet, valves, or washers, etc., to be made of the same ingredients as specified above for 8*a* quality rubber, except that the oxide of zinc is not to exceed 60 and the sulphur 1¾ per cent.

Vulcanized india-rubber tubing.—Except for special requirements the india-rubber for tubing is to be made of the following composition: Pure caoutchouc, of the quality specified at (*b*) above, sulphur and white oxide of zinc. No other ingredients whatever to be used in its manufacture. The sulphur not to exceed 3 per cent and the oxide of zinc 30 per cent; to endure a dry heat test of 270° F. for two hours without its quality being impaired. The canvas used in the manufacture of all the tubing subjected to internal pressure to be made of flax or fine hemp. The tubing is to satisfactorily withstand the stated pressure throughout its entire length, and is to be tested accordingly before being received.

Vulcanized india-rubber mats, perforated, to be made of pure caoutchouc of the quality specified at (*d*) above and with no other ingredients than sulphur and the oxides of lead and zinc; the sulphur not to exceed 2½ per cent, and the oxides of lead and zinc 60 per cent, in equal proportions; to endure a dry heat test of 270° F. for two hours without its quality being impaired.

India-rubber Solution.—The solution is to consist of pure best quality caoutchouc dissolved in good solvent mineral naphtha, which is free from tarry matter, and which is completely volatile at or below 290° F.; 100 parts by weight of the solution must contain not less than 13 parts by weight of rubber. The total mineral matter in the rubber solution must be under 0·1 per cent. Sulphur must be absent.

CANVAS.

All canvas articles are to be of good fit and well made. The tensile test, weight, etc., of the several numbers of canvas to be as follows:—

No.	Minimum Breaking Stress.		Weight per Bolt of 39 Yards for 1–6, and 40 Yards for 7.	Remarks.
	Weft.	Warp.		
	lb.	lb.	lb.	
1 R.N. . .	480	340	46	To be spun wholly from long flax.
2 " . .	460	320	43	
4 " . .	400	280	36	
6 " . .	350	250	30	
7 " . .	390	330	27	
No. 4 M.N. .	240	170	35	To be spun wholly from flax.
" 6 " .	210	150	30	
" 7 " .	195	140	27	

Length of strips for testing 2 feet by 1 inch for Nos. 1 to 6, and 2 feet by 1½ inches for No. 7 R.N.

Articles made of canvas are to be well sewn together with best flax twine coated with a composition of five parts of beeswax, four parts of palm-oil, and one of resin; if hand-sewn, to contain not less than 120 stitches to the yard.

Where holes and thimbles are fitted, the latter are to be of gunmetal; all brass gromets to be of spur teeth pattern. All painted articles to have three coats of best paint.

Manilla Cordage.

Manilla cordage is to conform to the table shown below, and to stand the breaking strain stated therein.

	Fathoms.	Degrees.
Length and angle at which strands are to be when formed	142	27
Length and angle at which strands are to be when hardened	134	33
Length and angle at which rope is to be when laid	113	39

Size of Rope.	Description of Yarn.	Total Number of Yarns in Rope.	Weight per Coil of 113 Fathoms.				Standard Breaking Strain.			
In.			Tons.	Cwt.	Qrs.	Lb.	Tons	Cwt.	Qrs.	Lb.
½	40 thread	6	0	0	0	10	0	3	3	0
¾	,,	12	0	0	0	20	0	7	2	0
1	,,	15	0	0	0	25	0	10	0	0
1¼	,,	21	0	0	1	5	0	12	2	0
1½	,,	33	0	0	1	24	0	18	3	0
1¾	,,	42	0	0	2	10	1	5	0	0
2	,,	54	0	0	3	1	1	13	0	0
2¼	,,	66	0	0	3	20	2	2	0	0
2½	,,	84	0	1	0	20	2	10	0	0
2¾	,,	102	0	1	1	21	3	2	0	0
3	,,	120	0	1	2	21	3	15	0	0
3½	30 thread	123	0	2	1	6	4	17	0	0
4	,,	159	0	2	3	25	6	5	0	0
4½	,,	201	0	3	3	1	8	1	0	0
5	,,	249	0	4	2	17	9	17	0	0
5½	,,	303	0	5	2	18	12	3	0	0
6	,,	351	0	6	2	26	14	7	0	0
6½	25 thread	360	0	7	3	14	16	0	0	0
7	,,	408	0	9	0	17	18	10	0	0
7½	,,	468	0	10	2	3	21	5	0	0
8	,,	534	0	11	3	25	24	5	0	0
9	,,	675	0	15	0	14	30	0	0	0
10	,,	834	0	18	2	22	37	10	0	0
11	,,	1,008	1	2	2	12	45	12	0	0
13	,,	1,407	1	11	2	6	63	15	0	0

LLOYD'S TESTS FOR MATERIALS.

Steel Plates.—To be made by the open-hearth process, acid or basic. To be finished free from cracks, surface flaws, and lamination. The tensile tests shall be made on a test piece prepared similarly to that described as 'A' (Admiralty tests, p. 265). The ultimate strength shall lie between the limits of 28 and 32 tons per square inch. The lower limit may be 26 tons for plates specially intended for cold flanging; the tensile tests may be dispensed with in material used where strength is unimportant. The elongation in 8 inches shall be at least 16 per cent below $\frac{3}{8}$ in. thick, and 20 per cent for thicker material.

The bend tests are the same as for the Admiralty (p. 265).

Steel Bars.—As steel plates, but the upper limit of tensile strength may be 33 tons per square inch.

Steel Rivets.—As for the Admiralty (p. 268), except that bars are to stand 25 to 30 tons per square inch.

Steel Castings.—The test pieces for tensile and bend tests are to be made as described in the Board of Trade Rules on p. 449. The ultimate tensile strength to lie between 26 and 35 tons per square inch, with an elongation of 20 per cent. To stand bending cold through 120°, with an internal radius of bend of 1 inch.

Stern frames cast in one piece to be raised through 45°, and let fall on hard ground recessed as necessary. Other important castings to be dropped through from 7 to 10 feet. Afterwards to be slung up, and hammered all over with a 7 lb. or heavier hammer to test the soundness of the casting.

Ingot Steel Forgings.—General requirements as for Admiralty (p. 271); but the test pieces to be as for steel castings above. The tensile breaking strength to be between 28 and 32 tons per square inch, with an elongation of 29 per cent for 28 ton steel, and 25 per cent for 32 ton steel; in no case must the sum of the tensile breaking strength and the percentage elongation be less than 57.

The bend test piece must stand bending over a radius of 4 in. through 180°.

Use of Iron.

The rivets, keel, stern, rudder, pillars, etc., also the floors, girders, and inner bottom in boiler space may be made of iron without increase of size. Deck plating, floors, double bottom structure in holds, bulkheads, engine casings, bulwarks, and deck houses may be made of iron 10 per cent thicker than the steel specified. Iron to be of good malleable quality, and subjected to shipyard tests.

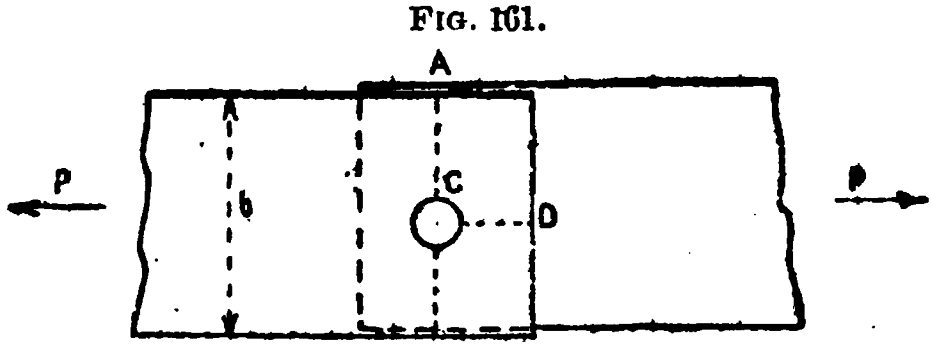
For Board of trade tests for materials for boilers, etc., see p. 449.

RIVETED JOINTS.

Design of Simple Riveted Joints.

A simple riveted joint may fail in several ways, as instanced by the lap joint with a single rivet shown in fig. 161.

Fig. 161.



(1) Plate can tear along AB.
(2) Rivet can shear.

(3) Plate can crush in front of rivet at C.

(4) Plate can tear along CD. This last is prevented when CD in the clear is at least equal to the rivet diameter.

t = thickness of plate in inches.

d = diameter of rivet hole in inches ($\frac{1}{32}$ in. to $\frac{1}{16}$ in. more than rivet diameter).

b = breadth of plate in inches.

P = pull on joint in tons.

(1) $P/(b-d)t$ = tensile strength of plate (26 to 28 mild steel).

(2) $P/\cdot 785d^2$ = shearing strength of rivet (about 22 mild steel).

(3) P/dt = bearing strength of rivet (about 40 mild steel).

Shearing and Bearing Values of Rivets (Working).

Mild Steel.

The stresses allowable in tons/inch² are taken as:—

Under single shear, shear 4, bearing 8.

Under double shear, shear 7·5, bearing 10.

These correspond to a factor of safety of 5; the corresponding allowable stress in plate would be 5 (Admiralty quality) or 5·5 (Lloyd's requirements).

In the table for single shear the bearing area has been assumed increased by 6 per cent to allow for the cone caused by punching; if the holes are rimered or drilled, reduce the bearing values by 6 per cent. If the rivets are countersunk increase the bearing values under single shear by 18 per cent.

Under dead loads a factor of safety of 3 is permissible; multiply all shear and bearing values by $1\frac{2}{3}$.

Mild Steel, single shear, punched holes.

Diameter of Rivet.	Assumed Diameter of Hole.	Area of Hole.	Shearing Value of one Rivet.	Bearing Value of Rivet. Weight of Plate in lb. per foot². 10	12½	15	17½	20	25	30	35	40
Inch	Inch	Inch²	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
$\frac{1}{2}$	$\frac{9}{16}$	·2485	·99	1·17*	1·46	1·76	2.05	2·34	2·93	3·52	4·10	4·69
$\frac{9}{16}$	$\frac{5}{8}$	·3068	1·23	1·30*	1·62*	1·95	2·28	2·60	3·25	3·90	4·55	5·21
$\frac{5}{8}$	$\frac{11}{16}$	·3712	1·48	1·43*	1·79*	2·15*	2.50	2·86	3·58	4·30	5·01	5·73
$\frac{11}{16}$	$\frac{3}{4}$	·4418	1·77	1·56	1·95	2·34*	2.73*	3·12	3·90	4·68	5·46	6·25
$\frac{3}{4}$	$\frac{13}{16}$	·5185	2·07	1·70	2·12	2·54*	2·96*	3·39*	4·24	5·08	5·93	6·73
$\frac{7}{8}$	$\frac{15}{16}$	·6903	2·76	1·96	2·44	2·93	3·42	3·91*	4·89*	5·86	6·84	7·83
1	$1\frac{1}{16}$	·887	3·56	2·22	2·78	3·33	3.88	4·44	5·55	6·66*	7·77*	8·88
$1\frac{1}{8}$	$1\frac{3}{16}$	1·107	4·43	2·46	3·08	3·69	4.30	4·92	6·15	7·38	8·61*	9·84*
$1\frac{1}{4}$	$1\frac{5}{16}$	1·353	5·41	2·74	3·42	4·11	4.79	5·47	6·84	8·21	9·58	10·94

Mild Steel, double shear, drilled holes.

Diameter of Rivet.	Assumed Diameter of Hole.	Area of Hole.	Shearing Value of one Rivet.	Bearing Value of Rivet. Weight of Plate in lb. per foot. 10	12½	15	17½	20	25	30	35	40
Inch	Inch	Inch²	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
$\frac{1}{2}$	$\frac{9}{16}$	·2485	1·86	1·38*	1·72	2·07	2·41	2·76	3·45	4·14	4·82	5·52
$\frac{9}{16}$	$\frac{5}{8}$	·3068	2·30	1·53*	1·91*	2·29	2·68	3·06	3·82	4·59	5·36	6·12
$\frac{5}{8}$	$\frac{11}{16}$	·3712	2·78	1·68*	2·11*	2·53*	2·95	3·37	4·21	5·06	5·90	6·74
$\frac{11}{16}$	$\frac{3}{4}$	·4418	3·31	1·84	2·30	2·76*	3·22*	3·68	4·60	5·52	6·44	7·36
$\frac{3}{4}$	$\frac{13}{16}$	·5185	3·88	1·99	2·49	2·98*	3·48*	3·98*	4·97	5·97	6·96	7·96
$\frac{7}{8}$	$\frac{15}{16}$	·6903	5·18	2·30	2·87	3·45	4·02	4·60	5·75*	6·90	8·05	9·20
1	$1\frac{1}{16}$	·887	6·65	2·60	3·25	3·91	4·56	5·21	6·51	7·81*	9·12	10·42
$1\frac{1}{8}$	$1\frac{3}{16}$	1·107	8·30	2·91	3·64	4·37	5·10	5·82	7·29	8·74	10·19*	11·64*
$1\frac{1}{4}$	$1\frac{5}{16}$	1·353	10·15	3·22	4·02	4·83	5·63	6·44	8·15	9·66	11·27	12·68

Note.—The bearing values to the right of the zigzag lines are greater than the shearing values, those to the left are less. To get the full value of the rivet shear, rivets must be selected from those to the right of these lines.

The values marked * are for rivets of the sizes usually adopted with the corresponding plates.

The table has been made complete, although certain rivet and plate sizes included therein would not be used together in practice.

High Tensile Steel—Cruiser quality (H.T., strength 34-38 tons/inch²).

Add 30 per cent to all the values given above for mild steel.

High Tensile Steel—Destroyer quality (H.H.T., strength 37-43 tons/inch²).

The stress allowable in tons/inch² are taken as :—

Under single shear, shear 7, bearing 9.

Under double shear, shear 13, bearing 11.

These correspond to a factor of safety of 5 ; the corresponding allowable stress in the plate would be 7. It is assumed that the rivets are also of H.H.T. steel.

All holes are assumed drilled. When countersunk increase the bearing value by 25 per cent.

Under dead loads multiply all shear and bearing values by $1\frac{2}{3}$.

H.H.T. Steel, single shear, drilled holes.

Diameter of Rivet.	Assumed Diameter of Hole.	Area of Hole.	Shearing Value of one Rivet.	Bearing Value of Rivet. Weight of Plate in lb. per foot². 6	7½	10	12½	15	17½	20
Inch	Inch	Inch ²	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
$\frac{5}{16}$	$\frac{11}{32}$	·0928	·64	·38*	·57	·76	·95	1·14	1·33	1·52
$\frac{3}{8}$	$\frac{13}{32}$	·1296	·91	·45*	·68*	·90	1·13	1·35	1·58	1·79
$\frac{7}{16}$	$\frac{15}{32}$	·1726	1·20	·52	·78*	1·04	1·30	1·56	1·82	2·07
$\frac{1}{2}$	$\frac{9}{16}$	·2485	1·74	·62	·93	1·24*	1·55	1·86	2·17	2·48
$\frac{9}{16}$	$\frac{5}{8}$	·3068	2·15	·69	1·04	1·38	1·73*	2·07	2·42	2·76
$\frac{5}{8}$	$\frac{11}{16}$	·3712	2·60	·76	1·14	1·52	1·90*	2·28*	2·66	3·04
$\frac{11}{16}$	$\frac{3}{4}$	·4418	3·09	·83	1·24	1·66	2·07	2·49	2·90*	3·31
$\frac{3}{4}$	$\frac{13}{16}$	·5185	3·63	·90	1·34	1·79	2·24	2·69	3·13	3·58*

H.H.T. Steel, double shear, drilled holes.

Diameter of Rivet.	Assumed Diameter of Hole.	Area of Hole.	Shearing Value of one Rivet.	Bearing Value of Rivet. Weight of Plate in lb. per foot². 6	7½	10	12½	15	17½	20
Inch	Inch	Inch ²	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
$\frac{5}{16}$	$\frac{11}{32}$	·0928	1·21	·46*	·70	·93	1·16	1·39	1·63	1·86
$\frac{3}{8}$	$\frac{13}{32}$	·1296	1·68	·55*	·82*	1·10	1·37	1·65	1·92	2·19
$\frac{7}{16}$	$\frac{15}{32}$	·1726	2·24	·63	·94*	1·26	1·57	1·89	2·20	2·53
$\frac{1}{2}$	$\frac{9}{16}$	·2485	3·23	·76	1·14	1·52*	1·90	2·28	2·66	3·03
$\frac{9}{16}$	$\frac{5}{8}$	·3068	3·99	·84	1·26	1·68	2·11*	2·52	2·95	3·37
$\frac{5}{8}$	$\frac{11}{16}$	·3712	4·83	·93	1·40	1·86	2·32*	2·79*	3·25	3·71
$\frac{11}{16}$	$\frac{3}{4}$	·4418	5·75	1·01	1·52	2·02	2·53	3·03	3·55*	4·05
$\frac{3}{4}$	$\frac{13}{16}$	·5185	6·73	1·10	1·65	2·20	2·75	3·30	3·85	4·39*

See notes under tables for mild steel.

Note also that all practicable sizes of rivets in double shear give way by excessive bearing pressure; double butt-straps are therefore of little use in this quality steel.

Rivets in Tension.

The value of such rivets depends very much on the size of the head and point. With hammered points the stress per square inch of *hole* area is about three-quarters that ordinarily

allowable in the material, provided that the pull is even so that there is little or no bending action on the rivet. This gives a working stress of 4 (mild steel) or 5½ (H.H.T. steel) tons per square inch under live loads.

If the pull is uneven take ·45 the usual stress, i.e. 2¼ (mild steel) and 3⅓ (H.H.T. steel) tons per square inch. In all cases the strength is uncertain, for it largely depends on the character of the workmanship.

For areas of holes for different-sized rivets see tables above.

SPACING OF RIVETS.

(*Lloyd's.*)

3½ diameters (centre to centre) in butts of outside plating and beam stringers (except quadruple butts).

4 diameters in edges of outside plating, quadruple riveted butt laps and double butt straps, butts and edges of inner bottom, butts of decks, margin and tie plates, girders and floors.

4½ diameters in gunwale and margin plate angles, edges and butts of bulkheads, edges of decks, angles between webs and side stringers.

5 diameters in angles to flat keel and connecting floors to centre girder, bulkhead frames where caulked, butts and edges of mast plates and floors.

6 diameters in deck plating to beams fitted to alternate frames.

7 diameters in frames (to be 6 diameters to outer bottom where depth is 11 inches or more, or spacing 26 inches or more), reverses, floors, keelsons, beam angles, deck and hold stringer angles, bulkhead stiffeners, various angles, and (generally) deck plating to beams.

(*Admiralty.*)

Maximum: 4½ diameters in oil-tight work, 5 diameters in W.T. work, 8 diameters otherwise.

Clear distance of rivet from edge of plate = one diameter + ⅛ in., generally, but one diameter + ¼ in. in destroyer butts.

THICKNESS OF BUTT STRAPS.

Lloyd's.—Up to ·30″ same as plate; above ·40″, 1·25 plate thickness; proportionately between ·30″ and ·40″. For double straps total thickness less thickness of single strap is about ·10″ for ½″ plate and ·02″ for 1¼″ plate and so intermediately; if one strap is countersunk make it about ·06″ thicker than the other.

Admiralty.—Generally same as plate. Exceptionally two straps are used with combined thickness 1⅛ times plate thickness.

For W.T. work one strap should generally be used.

Relation between Thickness of Plate, Size of Rivet, Breadth of Lap, etc.

(All dimensions in inches.)

Diameter of Rivet.	Lloyd's. Thickness of Plate.	Lloyd's. Breadth of Treble riv. butt straps.	Lloyd's. Breadth of Double riv. butt straps.	Lloyd's. Breadth of Treble riv. butt laps.	Lloyd's. Breadth of Double riv. butt laps.	Lloyd's. Breadth of Single riv. butt laps.	Lloyd's. Breadth of Double riv. edge laps.	Lloyd's. Breadth of Single riv. edge laps.	Admiralty. Thickness of Plate about	Admiralty. Breadth of Butt straps. Treble riv.	Admiralty. Breadth of Butt straps. Double riv.	Admiralty. Breadth of Butt straps. Single riv.	Admiralty. Breadth of Butt or edge laps. Treble riv.	Admiralty. Breadth of Butt or edge laps. Double riv.	Admiralty. Breadth of Butt or edge laps. Single riv.	Remarks.
5/16*	·10— ·14	—	4 1/4	—	2 1/8	1 1/4	—	1 1/4	—	—	—	—	—	—	—	Increase width of all butt straps by 1/2-in. and of all butt laps by 1/4-in. in T.B. Destroyers.
3/8*	·15— ·19	—	5	—	2 1/2	1 3/4	—	1 3/8	under ·15	6 1/2	4 1/2	2 3/4	3 1/4	2 1/4	1 3/8	
7/16*	·20— ·24	—	5 3/4	—	3	2	—	1 3/4	·15 to ·2	7 1/2	5 1/4	3 1/4	3 3/4	2 5/8	1 5/8	
1/2*	·25— ·29	—	6 1/2	—	3 1/2	2 1/4	—	2	·25	8 1/2	6	3 1/2	4 1/4	3	1 3/4	
9/16	—	—	—	—	—	—	—	—	·31	9 3/4	6 3/4	4	5	3 1/2	2	
5/8*	·30— ·34	—	8	—	4 1/4	2 1/2	—	2 1/4	—	—	—	—	—	—	—	
5/8	·22— ·34	—	8	—	4 1/4	2 1/2	3 3/4	2 1/4	·875	10 3/4	7 1/2	4 1/2	5 1/2	3 3/4	2 1/4	
11/16	—	—	—	—	—	—	—	—	·44	11 3/4	8 1/4	5	6	4 1/4	2 1/2	
3/4	·35— ·48	14 1/4	9 3/4	7 1/2	5	3	4 1/2	2 1/2	·5	12 3/4	9	5 1/4	6 1/2	4 1/2	2 3/4	
3/4*	·50— ·59	—	11 1/4	—	6	—	—	3	—	—	—	—	—	—	—	
7/8	·49— ·66	16 3/4	11 1/4	9	6	—	5 1/4	3	·625	15	10 1/2	6 1/4	7 1/2	5 1/4	3 1/4	
1	·67— ·88	19	—	10 1/2	—	—	6	—	·75 to ·875	17	12	7	8 1/2	6	3 1/2	
1 1/8	·89—1·14	21 1/2	—	12	—	—	6 3/4	—	1·0	19	13 1/2	8	9 1/2	6 3/4	4	
1 1/4	1·15—1·20	24	—	13 1/2	—	—	7 1/2	—	over 1·0	21 1/2	15	8 3/4	10 3/4	7 1/2	4 1/2	

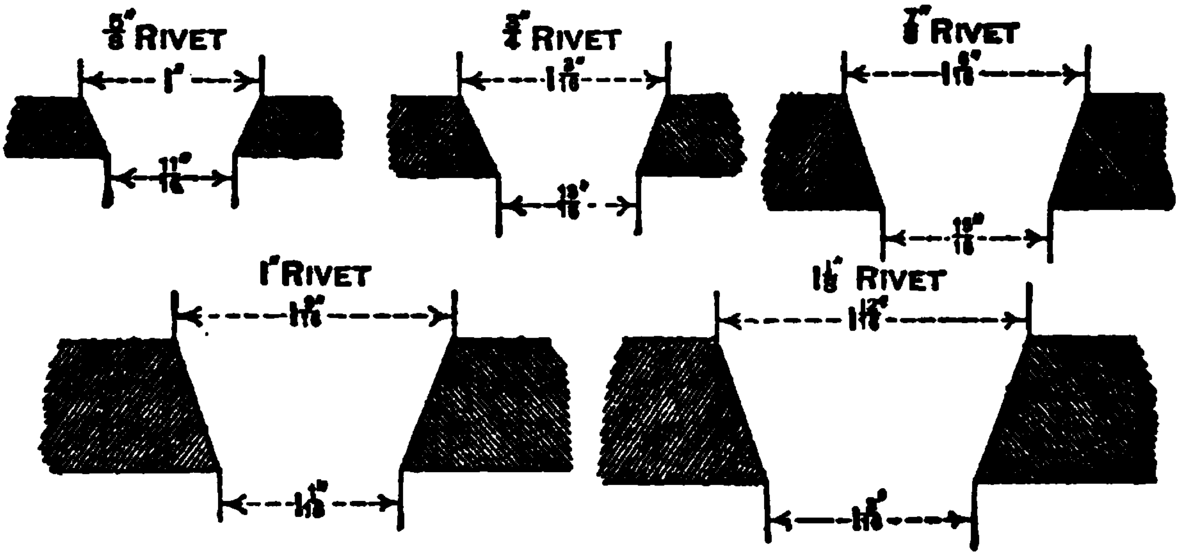
* These apply to yachts classified in the International Racing Classes.

Note.—The distance between adjacent rivet centres are (Lloyd's) butt straps 3 diam., butt laps 3 1/2 diam., edge laps 2 1/2 diam.; (Admiralty) 2 1/2 diam. in all cases. In zigzag seams distance between rows of rivets is 2 diam., centre to centre; breadth of lap about 5 1/2 diam.

Countersink of Rivets.

Lloyd's (for outside plating).—The proportions are as shown in fig. 162. The depth of countersink is $\frac{9}{10}$ plate thickness when ·60″ or more; if less, to be countersunk for full depth.

Fig. 162.



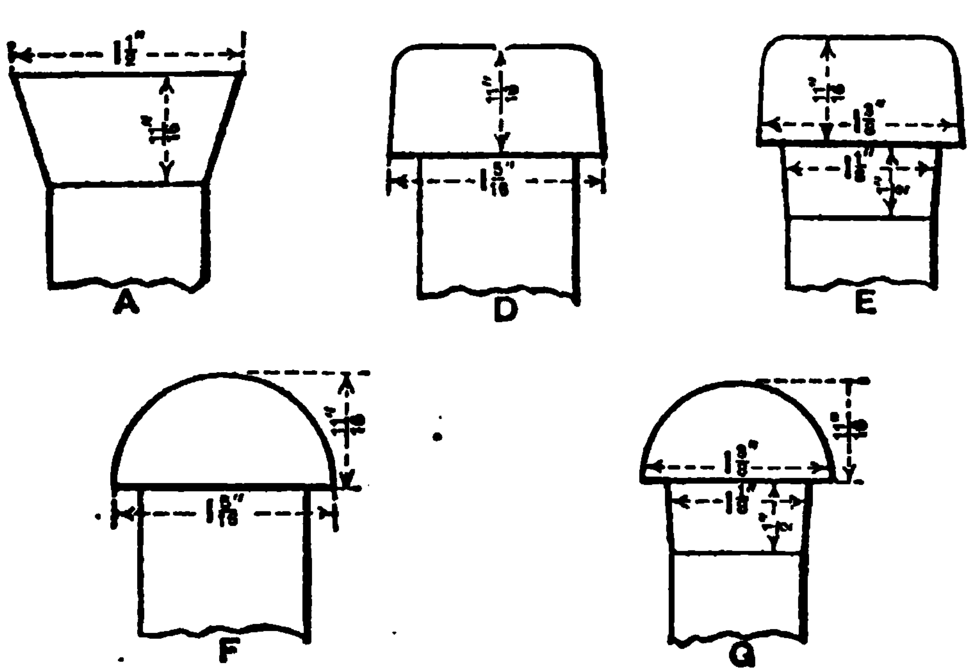
For yachts, the holes of rivets smaller than $\frac{5}{8}$″ are as follows:—

	in.	in.	in.	in.
Diameter of rivet . .	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
,, hole .	$\frac{6}{16}$	$\frac{7}{16}$	$\frac{8}{16}$	$\frac{9}{16}$
,, countersink	$\frac{9}{16}$	$\frac{10}{16}$	$\frac{12}{16}$	$\frac{13}{16}$

Admiralty practice.—Angle of countersunk point is equal to or slightly greater than that of countersunk neck (see below). Depth for thick plates about $\frac{1}{16}$″ less than that of plate.

Lengths and Proportions of Rivets.

Admiralty dimensions of 1 inch rivets of the several descriptions are specified in the schedule below.



SCHEDULE OF DIMENSIONS.

Diameter of Rivet	With Pan or Snap Head and Straight Necks, to Drawing D or F		With Countersunk Head, to Drawing A		With Pan or Snap Heads and Conical Necks, to Drawing E or G			
	Diameter of Head	Depth of Head	Diameter of Head	Depth of Head	Diameter of Head	Depth of Head	Diameter under Head	Depth of Cone
Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch
$1\frac{3}{8}$	$1\frac{15}{16}$	1	—	—	2	1	$1\frac{1}{2}$	$\frac{5}{8}$
$1\frac{1}{4}$	$1\frac{11}{16}$	$\frac{7}{8}$	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{7}{8}$	$1\frac{3}{8}$	$\frac{9}{16}$
$1\frac{1}{8}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{4}$	$1\frac{9}{16}$	$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{2}$
1	$1\frac{5}{16}$	$\frac{11}{16}$	$1\frac{1}{2}$	$\frac{11}{16}$	$1\frac{3}{8}$	$\frac{11}{16}$	$1\frac{1}{8}$	$\frac{1}{2}$
$\frac{7}{8}$	$1\frac{3}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$‡	$\frac{5}{8}$	$\frac{15}{16}$	$\frac{7}{16}$
$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{9}{16}$	$1\frac{1}{8}$	$\frac{7}{16}$	$1\frac{1}{16}$	$\frac{9}{16}$	$\frac{13}{16}$	$\frac{3}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{1}{2}$	1	$\frac{5}{16}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{5}{16}$
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{1}{4}$
$\frac{7}{16}$	$\frac{11}{16}$	$\frac{3}{8}$	—	—	—	—	—	—
$\frac{3}{8}$	$\frac{5}{8}$*	$\frac{5}{16}$**	$\frac{5}{8}$	$\frac{1}{4}$	—	—	—	—
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{1}{4}$†	—	—	—	—	—	—
$\frac{1}{4}$	$\frac{7}{16}$	$\frac{3}{16}$	—	—	—	—	—	—
$\frac{3}{16}$	$\frac{3}{8}$	$\frac{1}{8}$	—	—	—	—	—	—

* $\frac{9}{16}$ in. for snap heads. ** $\frac{1}{4}$ in. for pan heads
† $\frac{3}{16}$ in. for pan heads. ‡ $1\frac{3}{16}$ in. for pan heads.

Lloyd's.—The rivets specified for use in outside plating have pan heads and conical necks with the following dimensions: Diameter of rivet d, diameter of top of head d, diameter of bottom of head $1\cdot6d$, depth of head $\cdot7d$, diameter of top of neck $1\cdot12d$, depth of neck to suit thickness of plating.

LENGTHS FOR ORDERING.

The lengths under heads of various descriptions of rivets for two thicknesses of plates may be determined as follows:—

Countersunk points about $\frac{3}{4}$ diameter greater than length of hole; snap hydraulic points about $1\frac{1}{2}$ diameters greater than length of hole; rough hammered points about $\frac{7}{8}$ of the diameter greater than length of hole.

For three thicknesses allow $\frac{1}{8}''$ more; and for any unusual length proportionately.

DESIGN OF RIVETED JOINTS IN GENERAL.

Treble riveted butt connections may be broken in five different ways, see fig. 162 A.

(1) The plate may break through the line *a a*.

(2) The strap may break through the line *b b*.

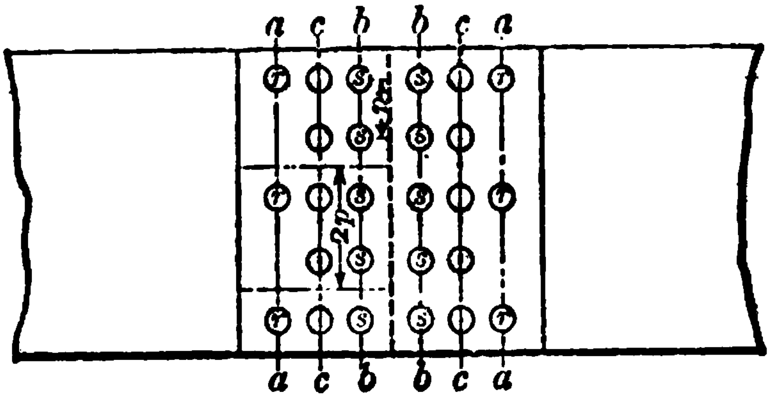
(3) The plate may break through the line *c c* and shear rivets *r*, *r*.

(4) The butt strap may break through line $o\,o$ and shear rivets s, s.

(5) All rivets may shear on one side of butt strap.

Usually (3) and (4) need not be considered.

FIG. 162A.



The strength on the basis of (1), (2), and (5) should be about the same; frequently the strength with (5) is made rather greater than the other two. To obtain deduction for rivet holes from plate area, increase diameter of hole by 6 per cent if punched, and by 25 per cent if countersunk.

The least rivet spacing desirable is about $3\frac{1}{2}$ diameters between centres.

Example.—A 30 lb. stringer plate 4 feet wide is to have a double butt strap. Design the joint, given that the plate is already pierced with beam rivets spaced 8 diameters.

Take 1″ rivets or $1\frac{1}{16}$″ holes. Assume holes for beam rivets to be countersunk; there are 6 rivets. Working strength of plate at 5 tons/inch^2 $= 5 \times \frac{3}{4} \times (48 - \overline{\frac{17}{16} \times 1\frac{1}{4} \times 6}) = 150$ tons. Taking mild steel double shear, shear value (from table, p. 287) per rivet is 6·65, and bearing value is 7·81. Take the smaller. Least number of rivets is 150/6·65 = about 23.

A convenient arrangement will be found with 28 rivets in rows of 6, 11, and 11. The outer row having only 6 rivets makes plate when breaking as in (1) as strong as through beam holes.

To get combined thickness (t) of straps, allow punched holes in one strap and countersunk holes in the other. Mean percentage increase of hole diameter is $\frac{1}{2}$ (6 + 25) or 15.

Hence $t \times (48 - \overline{1{\cdot}15 \times \frac{17}{16} \times 11}) = \frac{150}{5}$, or $t = {\cdot}87$. Straps should each be ·43″ or approximately $17\frac{1}{2}$ lb.

Note.—If the plate is unweakened, the strongest possible strap is diamond-shaped.

In the joints (figs. 162B and C) the strength of the plate is only weakened by the extent of one rivet hole. Double butt straps should be fitted if this standard of strength is to be maintained.

Zigzag Riveting.

The clear area of the plate between zigzag rivets should be 35 per cent greater than that required directly across the

plate. In high tensile steel, destroyer quality, this percentage should be 50.

This apparent weakening along the diagonal should be allowed for when determining the rivet spacing of ordinary joints, if for any reason the rows are placed unusually close together.

FIG. 162B.

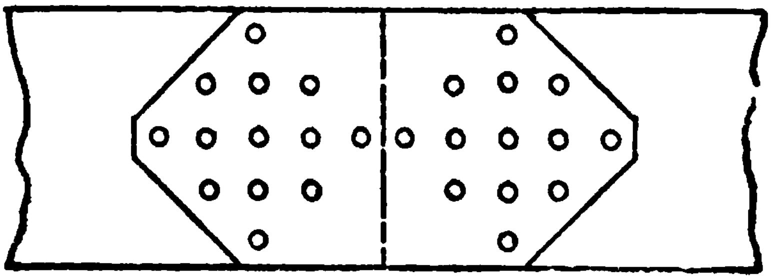
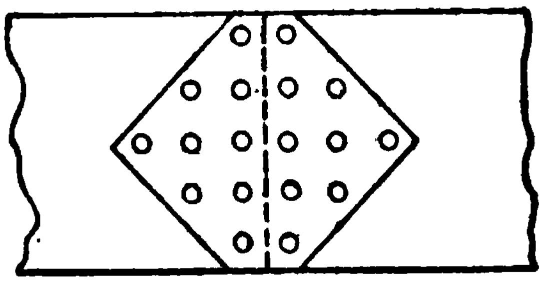


FIG. 162C.



Effect of punching, drilling, and annealing.

In mild steel punching lowers the ultimate strength while drilling raises it. Since the latter effect can only be due to circumstances which do not influence the elastic or working stress, it may be inferred that the real loss of strength due to punching is about 20 or 25 per cent. This is partly restored by hot riveting, and wholly restored by annealing or rimering.

In high tensile steel punching is even more deleterious.

BRACED STRUCTURES.

Certain types of structures or girders consist of a number of pieces jointed together by pins. If the joints can, without large error, be regarded as frictionless, and each piece or member has no more than two pin joints, the stresses are wholly those of tension or compression along the lines joining the pin centres, provided that the loads are assumed concentrated at the joints.

If number of members $=$ ($2 \times$ number of pins) -3, the structure is termed a perfect frame. Its stresses can be determined by elementary statics.

If the number of members is less than that given by the above formula, the structure is termed an incomplete frame. It is free to move, and the stresses depend on the position taken up, and conversely; e.g. chain, suspension bridge.

If the number of members is greater than that given by the formula, the structure is termed an overbraced frame. It may be self-stressed, and unless some members be

disregarded as redundant, the determination of the stresses involves a knowledge of the elastic properties of the material of the members; e.g. many types of boats' slings.

Perfect Frames.

If the loads are not placed at the joints, divide that on each member into two equivalent portions at the two joints.

To find the stresses by a reciprocal diagram.—Determine the external reactions (if unknown) and represent them by lines on the diagram. Let the *spaces* on the diagram be lettered by large letters A, B, C, D . . . separated either by members of the frame or by external reactions. Then AB represents the reaction on the member separated by the

Fig. 163 (1).

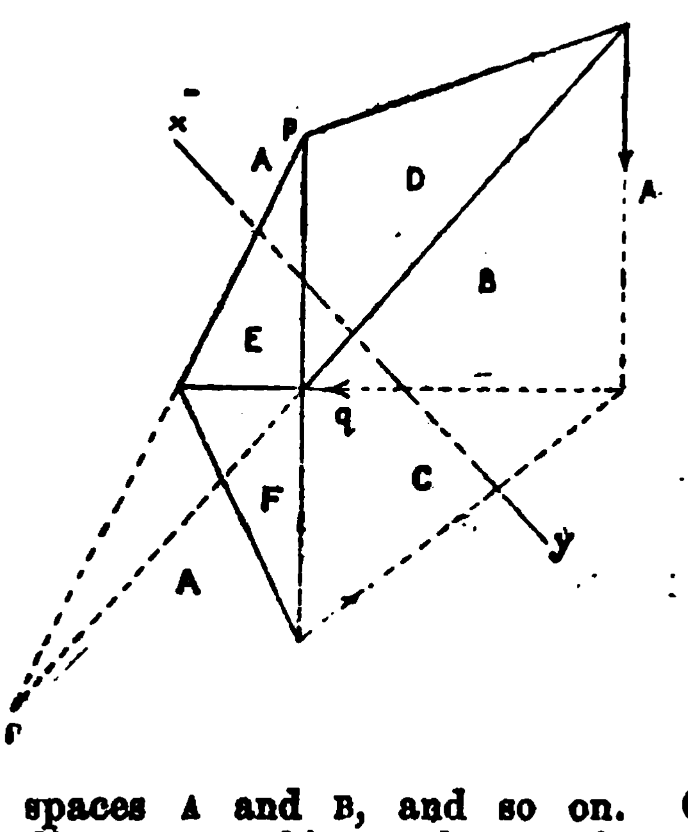
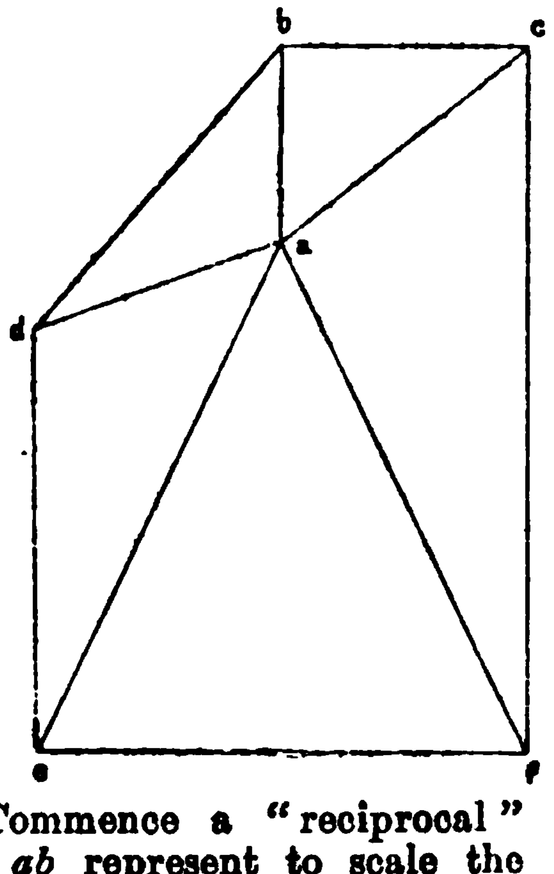


Fig. 163 (2).



spaces A and B, and so on. Commence a "reciprocal" diagram, making a known force *ab* represent to scale the force AB, and parallel to it (fig. 163). Then draw *ad* in the reciprocal diagram parallel to AD, and *bd* parallel to BD. Let *ad, bd* intersect at *d*. Then these will represent the stresses in AD and BD respectively. Continue thus with the next letter, and so on until the reciprocal diagram is finished and all the stresses are known. A simple examination will show which members are in tension, and which are in compression.

To find the stresses by the method of sections.—To determine the stresses in any one member (as, for example, in certain cases when the above method is inapplicable), divide the structure in two by a line cutting through not more than three members, including the one whose stress is desired.

Find the point of intersection of the other two members (produced if necessary) and take moments about it for all the external forces on *one* side of the section, including the unknown stress in the member cut. Then the stress in the member is determined by the fact that the algebraical sum of the moments is zero. If the other two members are parallel, resolve the external forces perpendicular to their direction.

Example.—In fig. 163, to find the stress in DE, draw a section *xy* cutting through it, and through AE, BD in addition. These two latter intersect at *r*. By taking moments about *r* of the external forces on one side, i.e. *either* BC, AC to the left *or* AB to the right, and of the unknown force DE, and equating to zero, the unknown force is obtained. Here force DE × its perpendicular distance from *r* is equal and opposite to the moment of AB about *p*. Similarly, AE is found by taking moments about *q*, and BD by taking moments about *p*. If AE and BD were parallel, DE would be found by resolving the forces on one side perpendicular to AE.

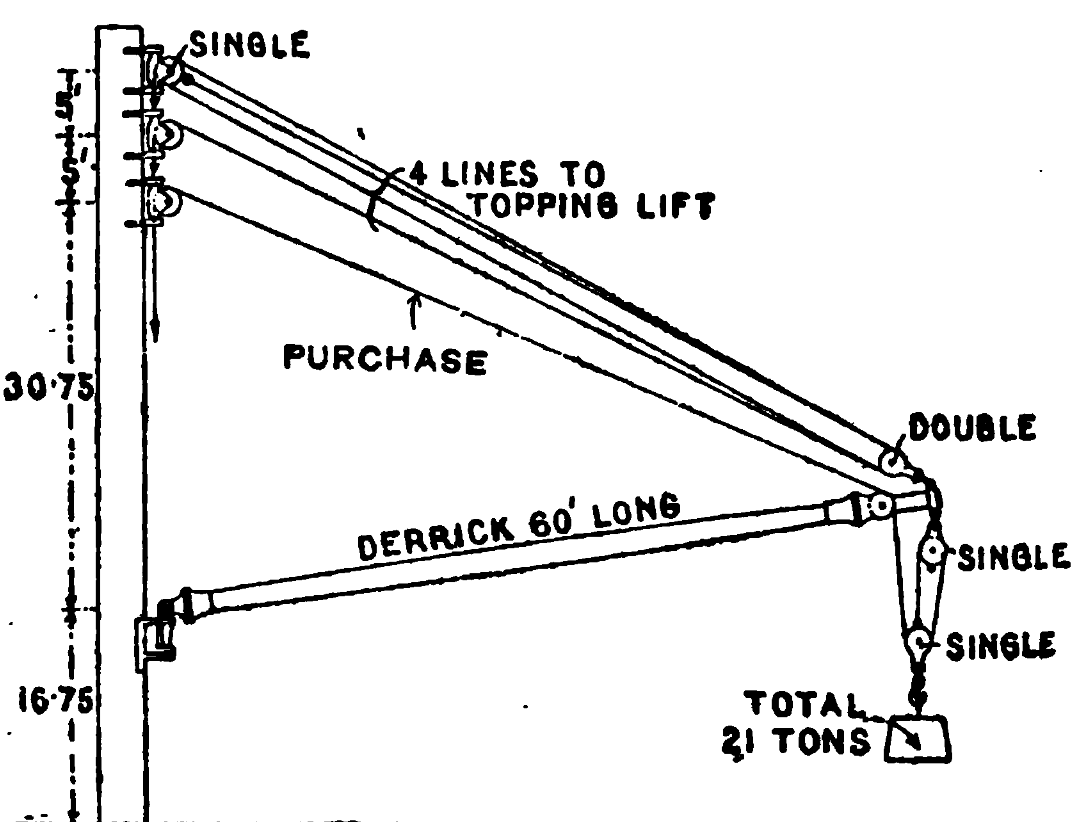
Note.—If any member of the structure have joints at more than two points, it must be treated as a beam. In that case deal with the forces on each side by the method above, and put their total resultants and moments equal to zero.

Ship's Derrick.

To find stresses in parts.

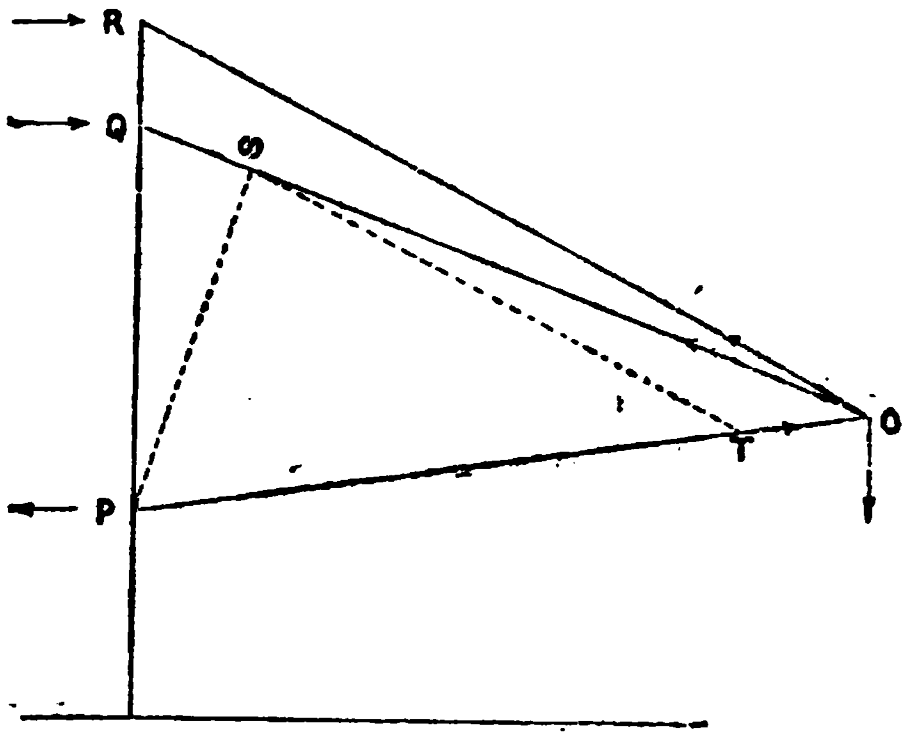
Rule.—Find the tension in all parts of purchase. This is deduced from the load lifted ; it is usually assumed that the

Fig. 164.



friction of the blocks increases the tension by 10 per cent* at each turn, and that the load is being lifted. Draw OQ (fig. 165) to represent in a diagram the direction of the purchase (shown in fig. 164). Draw OR to represent the

FIG. 165.



mean direction of the topping lift for the particular position OP of the derrick. Without great error the purchase and topping lift lines may be taken to intersect at the end of the derrick O.

Choose a scale such that PQ = total vertical load lifted, on this scale set off QS = tension in purchase OQ. Join PS, and draw ST parallel to OR. The polygon PQST is the reciprocal diagram for the forces on the end of derrick; and on the scale above, ST = total pull in topping lift and PT = thrust in derrick. From these data, the sizes of derrick and of steel wire rope for purchase and topping lift may be determined. The maximum B.M. on mast, if not stayed = vertical load at O × horizontal distance of O from mast.

Example.—To proportion the parts of a battleship's derrick shown in fig. 164. The load consists of—

		Tons.
Actual load (maximum)	=	16·0
Proportion of weight of derrick = $\frac{33}{60}$ × 7 tons	=	3·8
3 blocks	=	·9
Wire in portions of purchase and topping lift	=	·3
Total weight to be lifted	=	21·0

Total to be lifted by purchase = 16·0 + ·3 (one block) = 16·3 tons. The latter load is borne by three vertical lines,

* This is an extreme estimate; the actual loss of power is generally much less.

mean pull $\frac{1}{3} \times 16{\cdot}3 = 5{\cdot}4$; so that their actual tensions are (allowing 10 per cent friction for each turn) 4·9, 5·4, and 6·0 tons; tension in portion OQ of purchase $= 6 + 10$ per cent $= 6{\cdot}6$ tons.

In fig. 165 put R at about $\frac{2}{3}$ the distance up between the two highest blocks in the mast. Find the scale that will make PQ $= 21$ tons; this will be the scale of the force diagram. Make QS $= 6{\cdot}6$ tons. Draw ST parallel to OR and measure ST and PT.

Repeat this process for several positions of the derrick. It will be found that the thrust in derrick is nearly constant —say 35 tons; and that the total pull in topping lift is a maximum when derrick is as low as possible (here 8° to horizontal); take it as 30 tons. The maximum tension in topping lift is (allowing for friction) $\frac{30}{4} +$ about 15 per cent $= 8{\cdot}6$ tons.

A factor of safety of 6 or more is usual in steel wire rope; here 4″ rope breaking at 58 tons could be used.

The section of derrick at middle should be sufficient in the basis of the formula for pillars (p. 328), omitting the area of stiffeners, but omitting also the term $N\rho/t$ since the stiffeners serve the purpose of preventing local collapse.

To find greatest height of purchase block for stability of derrick when topped.

RULE.—The height of block Q (fig. 165) above the heel of the derrick must not be greater than PO—QS. Since QS/QP is the ratio of tension in purchase to load, and is equal to n (say), where n is about ·3 in ordinary cases, PQ must not exceed the length of derrick divided by $(1 + n)$.

In the example, $n = 6{\cdot}6/21 = {\cdot}31$. Hence PQ should be less than 60/1·31 or 45 feet. Actually PQ $= 30$ feet.

SHEER LEGS.

Let W be the load lifted, including half the weight of the sheer legs.

In fig. 166, OC is the back leg, OD the perpendicular from O to the line joining the feet of the front legs OA, OB. OM is vertical. The forces at O in the plane of the figure may be graphically determined by means of a triangle of forces or reciprocal diagram.

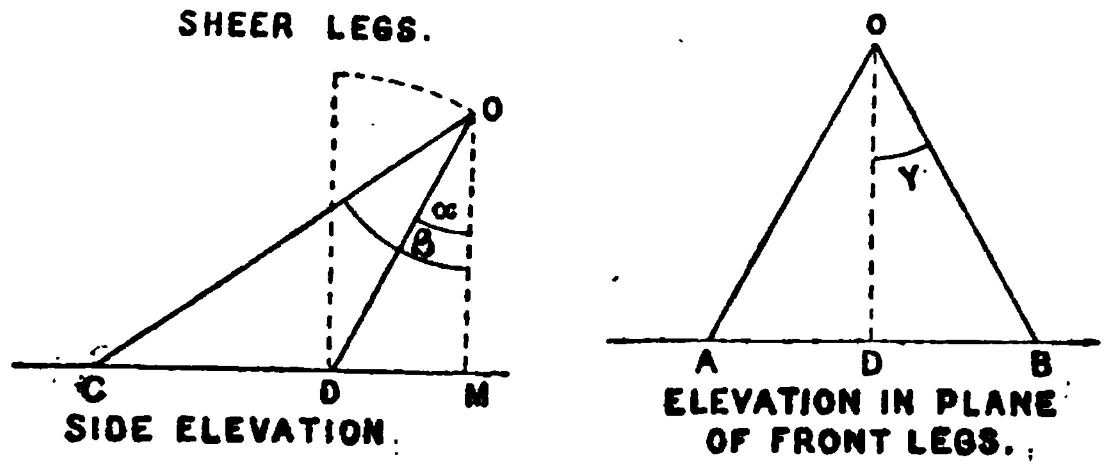
Alternatively if α, β, γ represent the three angles MOD, MOC, DOB, then

$$\text{Pull in back leg} = \frac{W \sin \alpha}{\sin(\beta - \alpha)}$$

$$\text{Thrust in each front leg} = \frac{W \sin \beta}{2 \sin(\beta - \alpha)} \sec \gamma.$$

Horizontal force required at C, the foot of the back leg, is equal to $\frac{W \sin \alpha}{\sin (\beta - \alpha)} \{\sin \beta \pm \mu \cos \beta\}$; where μ is the coefficient of friction at C, say ·15. Take plus sign if sheer legs are being topped, and conversely.

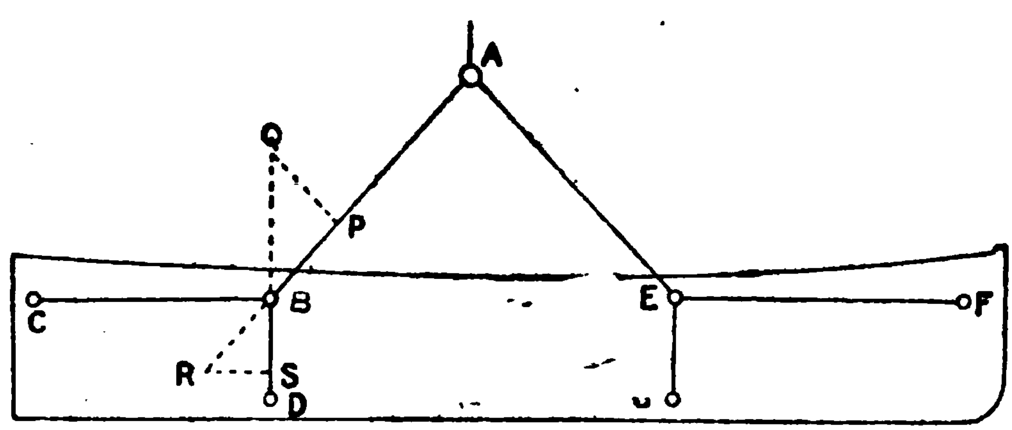
FIG. 166.



BOATS' SLINGS.

In heavy pulling boats not lowered from davits, the sling shown in fig. 167 is frequently adopted. The stresses are readily obtained, as shown (for one side) in the figure. BQ represents weight of boat; QP is parallel to AE and gives the stress in that member; BP gives that in AB. Similarly RB = BP, RS is parallel to BC: and RS, BS give the tensions in BC and BD.

FIG. 167.

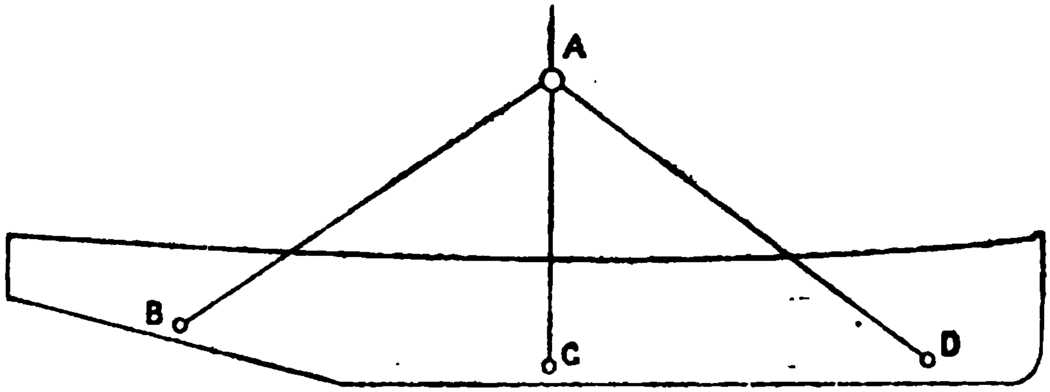


Each portion of the sling is proof-tested to double its working load.

In steam- and motor-boats, the sling shown in fig. 168 is sometimes used. The stresses are here indeterminate, for they depend on the adjustment of the length of AC. This should be arranged so that the boat is deflected as little as possible when slung. The middle leg AC should be capable of supporting (say) $\frac{2}{3}$ the whole weight; the other two legs AB, AD, should

be capable of supporting ½ the weight, for the distribution of the tensions is uncertain.

FIG. 168.



Example.—A boat weighing 15 tons when fully equipped is hoisted by means of a sling of the type shown in fig. 168; the angles BAC and DAC are each 45°. Determine the sizes of wire rope, etc.

Working tension in AC is 10 tons, and in AB or AD is $5\sqrt{2}$ or 7 tons. Allowing a factor of safety of 4, it appears that the wire rope AC should be about 4½″ circumference; AB and AD would probably be made the same size for convenience, but their size could be safely reduced to 3½″.

The ring A should be proof-tested to 30 tons, and the sling fittings at B and D to 15 tons, and at C to 20 tons. Using the formula on page 338, it appears that if the mean diameter of the ring A be 12″, the diameter of the iron should be 2¾″.

SHEARING FORCES AND BENDING MOMENTS OF BEAMS.

Shearing force.—At any section this is the total force tending to break the beam in the manner shown in fig. 169. It is equal to the algebraic sum of all the forces acting

FIG. 169.

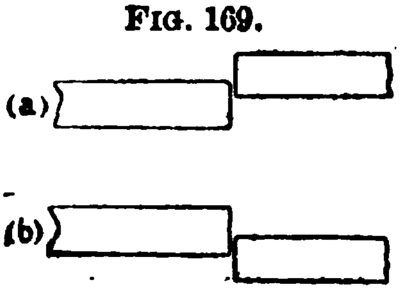
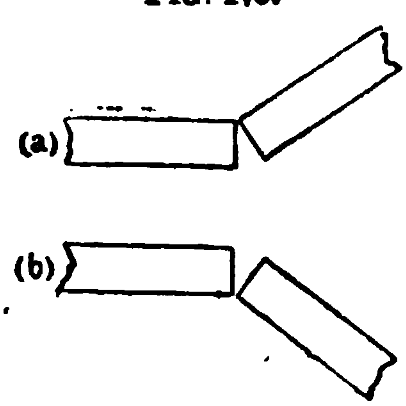


FIG. 170.



between that section and either end of the beam. For distributed loads of weight w per unit length, the shearing

force F is given by the formula— $F = \int w\,dx$, when dx is an element of length.

Bending moment.—At any section this is the total couple tending to break the beam in the manner shown in fig. 170. It is equal to the algebraic sum of the moments of all the forces acting between that section and either end of the beam. It is also equal to the area of the shearing force up to that section. For distributed loads the bending moment M is given by the formulæ—

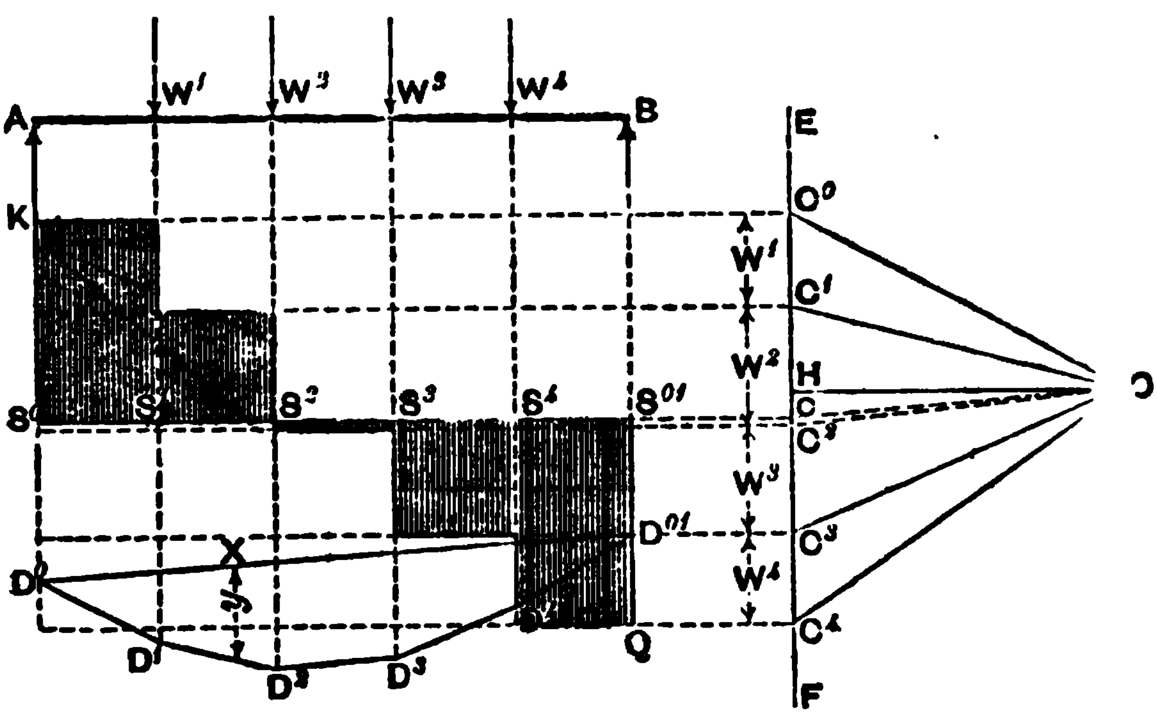
$$M = \int w\,x\,dx \text{ or } M = \int F\,dx.$$

Note.—Since loads act usually downwards, downward forces are regarded as positive, and are set off on the positive side, i.e. *below* the beam. Similarly + shearing forces (represented by (*b*) in fig. 169) and + bending moments (represented by (*b*) in fig. 170) are set off below the beam.

Graphical Method of determining the Bending Moments and Shearing Forces in a Beam.

Concentrated Loads acting at various points.

FIG. 171.



In fig. 171 AB represents the beam supported at points A and B. Set off continuously along a line EF, the forces W^1, W^2, W^3, W^4 $= C^0\,C^4$, the resultant of the forces. Take any point O, and join

OC^0, OC^1, ... OC^4, &c. Draw the parallel lines AD^0, WD^1, . . . BD^0 through the lines of action of the forces. Take any point, D^0 in AD^0, and draw D^0, D^1 parallel to OC^0, D^1, D^2 parallel to OC^1, . . . D^4, D^{01} parallel to OC^4. Join D^0, D^{01}, completing the funicular polygon D^0, D^3, D^{01}. Draw a line OC parallel to D^0, D^{01}, cutting EF in C; then C^0C equals the supporting force at A, and CC^4 equals the supporting force at B. Also through O draw OH perpendicular to EF.

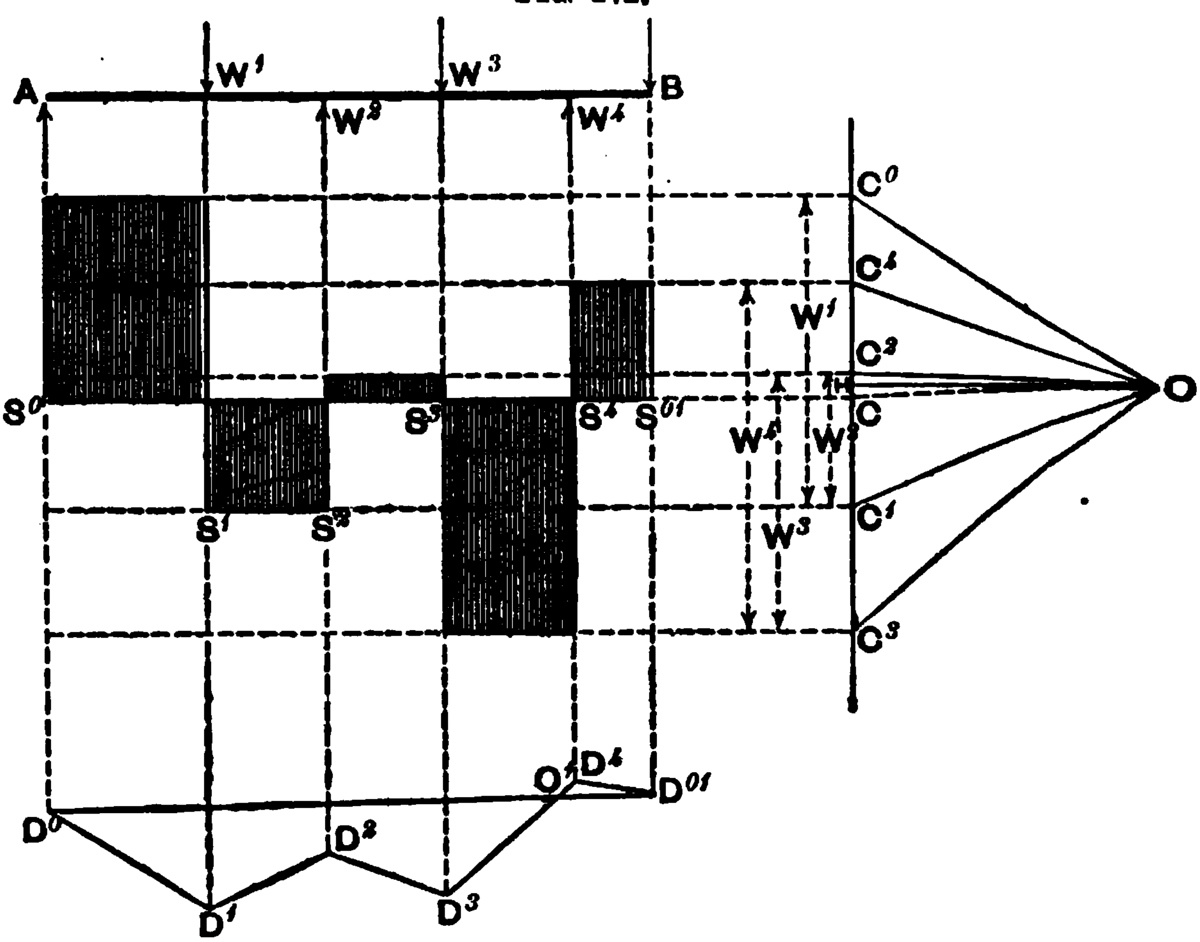
Through the points C^0, C^1, . . . C^4 drop perpendiculars on to AD^0, W^1D^1, . . . BD^{10}, and form the hatched figure $S^0KS^2QS^{01}$. Then the vertical ordinate of this diagram, measured at any point in the length of the beam, gives the shearing force at that point, measured on the same scale as used for setting off W^1, W^2, &c.

To obtain the bending moment at any point X make a scale as follows:—

If beam is drawn to a scale 1 foot $= x$ inches; and loads are drawn to a scale 1 pound $= z$ inches, then the ordinate 'y' of the funicular polygon is the bending moment at the point X on a scale such that 1 foot-pound is $= \frac{x \times y}{OH}$, in inches always; OH is measured on an inch scale.

Forces acting in different directions.

FIG. 172.



These diagrams are constructed in a similar manner to (fig. 171), the lengths of the forces being also set off in the direction

of their line of action. c^0c is the supporting force at A, and cc^4 the holding down force at B as it lies to the left of c—that is, it is measured in the opposite direction to c^0c^4; the bending moment at any point o^1 where the sides of the funicular polygon cross is zero, and the bending moments to the left of o^1 are in the opposite direction to those on the right of o^1.

TABLE OF GRAPHICAL BENDING MOMENTS AND SHEARING FORCES OF BEAMS.

W = load. L = length of beam.

w = uniform intensity of load.

M = maximum bending moment.

m = bending moment at any section.

S_1 = maximum shearing force.

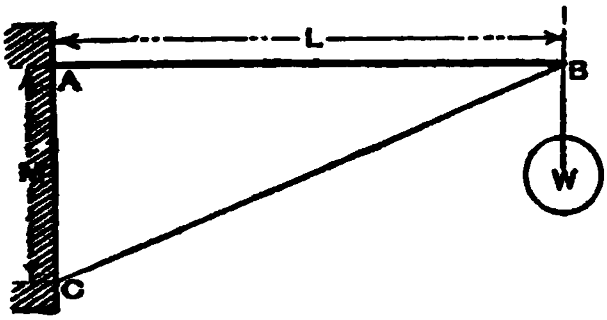
S = shearing force at any section.

The diagrams are constructed by setting off to scale M, and S_1, or S; then the ordinate measured at any point represents the moment or shearing force at that section.

Bending Moment	Shearing Force

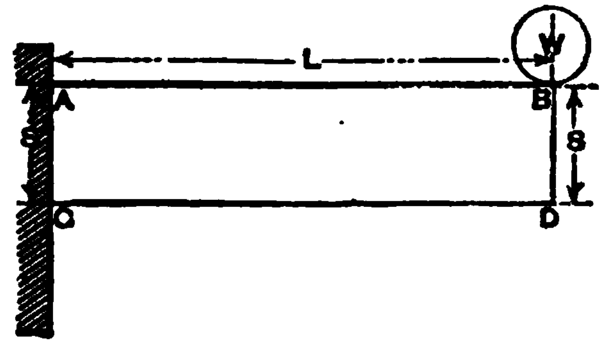
Fixed at one end, loaded at the other.

FIG. 173.



Set down M = WL, and join BC.

FIG. 174.



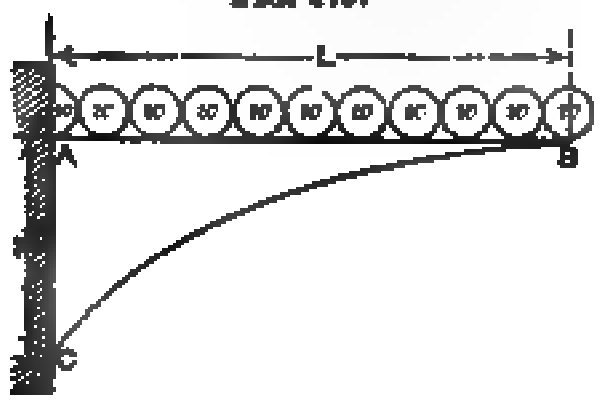
Set down S = W parallel to AC.

Table of Graphical Bending Moments, &c.—*cont.*

Bending Moments	Shearing Forces

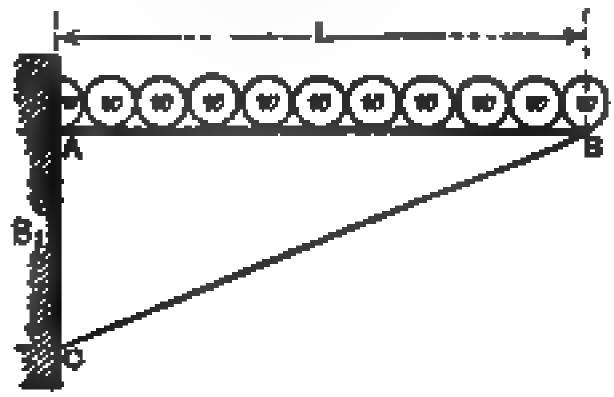
Fixed at one end and loaded uniformly.

Fig. 175.



Set off $M = \frac{wL^2}{2}$; draw the parabola BC, whose vertex is at B.

Fig. 176.



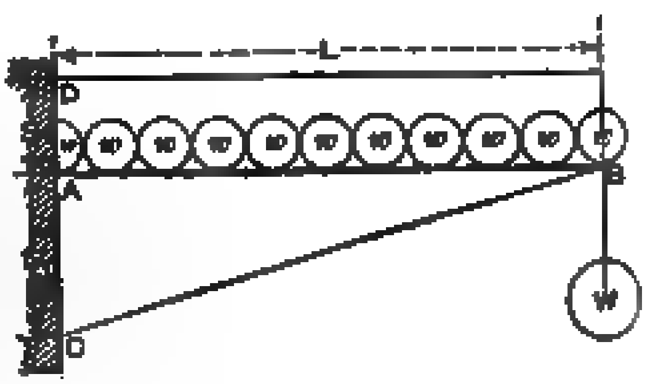
Set off $S_1 = wL$, and join BC.

Fixed at one end, uniformly loaded, with additional weight at one end.

Fig. 177.

Set off $M = WL$, and $M_1 = \frac{wL^2}{2}$. Join DB, and construct the parabola BC whose vertex is at B.

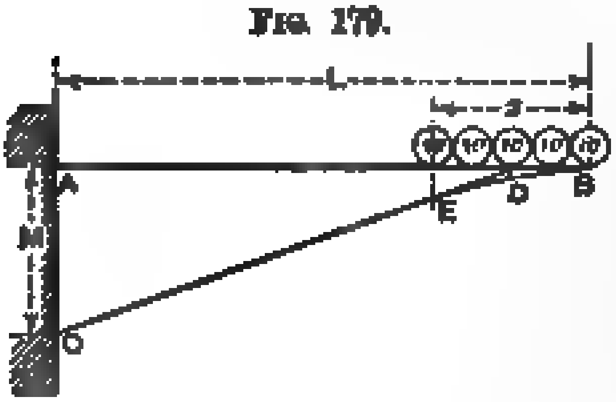
Fig. 178.



Set off $S = W$, and $S_1 = wL$. Join BC. Construct parallelogram ADEB.

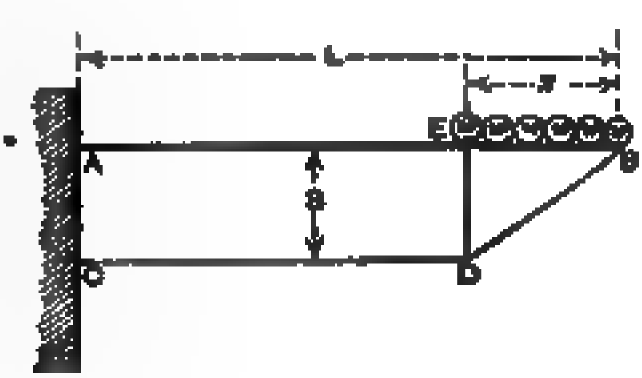
Fixed at one end, partially uniformly loaded.

Fig. 179.



Set off $M = wz\left(L - \frac{z}{2}\right)$. Join C to a point D at middle of load. Draw BE, a semiparabola, as for a beam uniformly loaded of a length z.

Fig. 180.



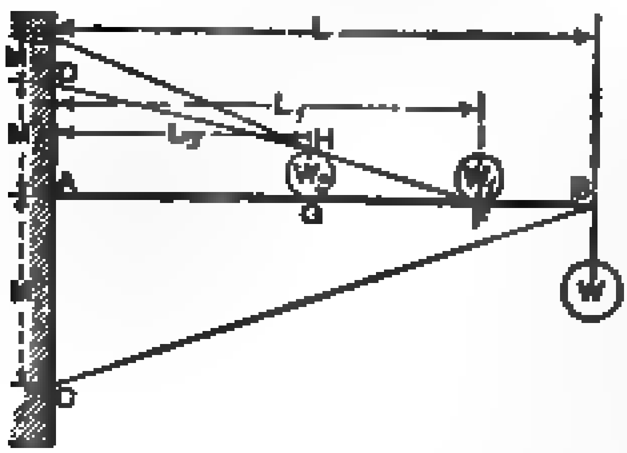
Set off the rectangle ACED, making $S = wz$, and join BD.

Table of Graphical Bending Moments, &c.—*cont.*

Bending Moments	Shearing Forces

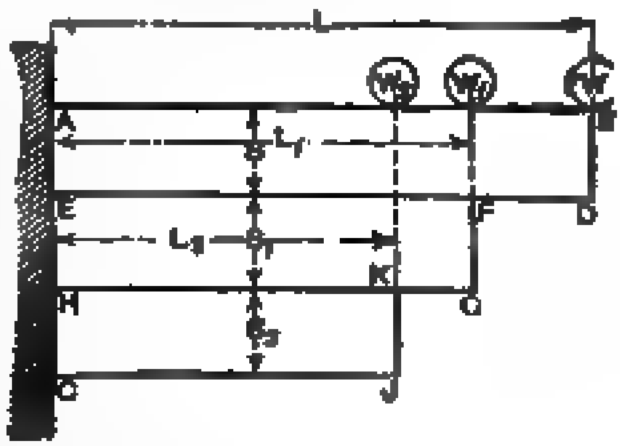
Fixed at one end with several concentrated loads.

Fig. 181.



Set off $M = WL$, $M_1 = W_1L_1$, $M_2 = W_2L_2$. Join B to C, F to D, and E to H. The bending moment is equal to the sum of the bending moments at the section produced by each load separately.

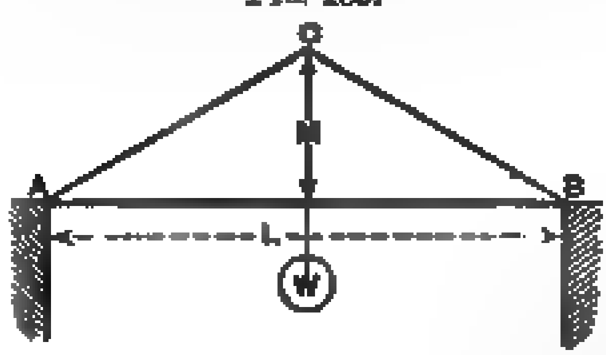
Fig. 182.



Set off $S = W$, $S_1 = W_1$, $S_2 = W_2$ and construct the rectangles ABDE, EFGH, and HKCJ.

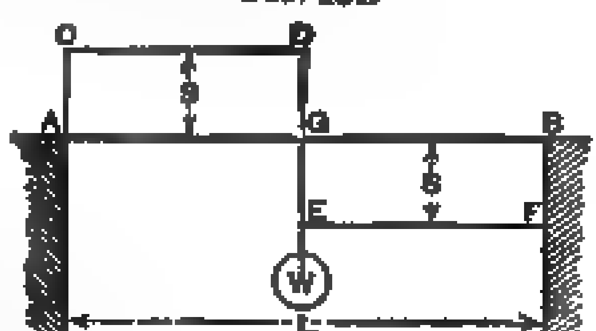
Supported at both ends, loaded at centre.

Fig. 183.



Set off $M = \frac{WL}{4}$. Join AC and BC.

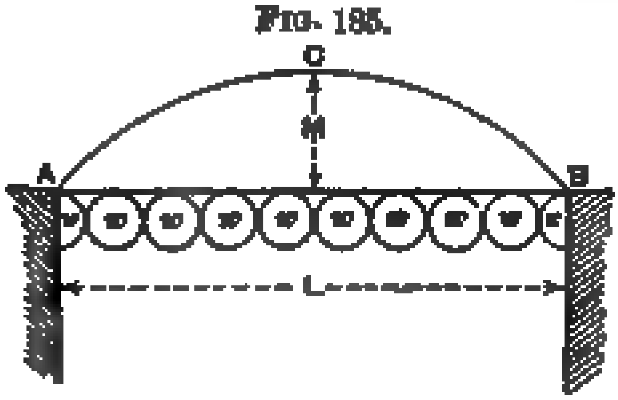
Fig. 184.



Set off S and $S = \frac{W}{2}$, and construct the rectangles ACDG and BGFE.

Supported at both ends, uniformly loaded.

Fig. 185.



Set off $M = \frac{wL^2}{8}$, and construct the parabola ACB, whose middle ordinate is at C.

Fig. 186.

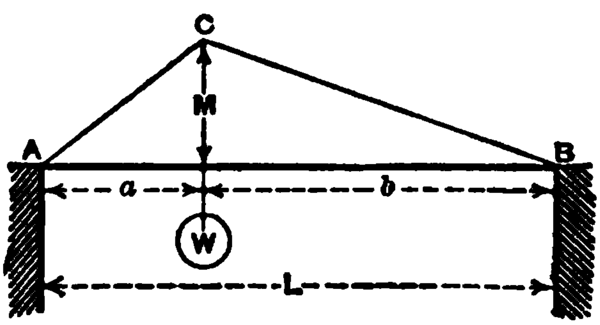
Set off S_1 above and S_1 below $= \frac{wL}{2}$, and join DC.

Table of Graphical Bending Moments, &c.—*cont.*

Bending Moments	Shearing Forces

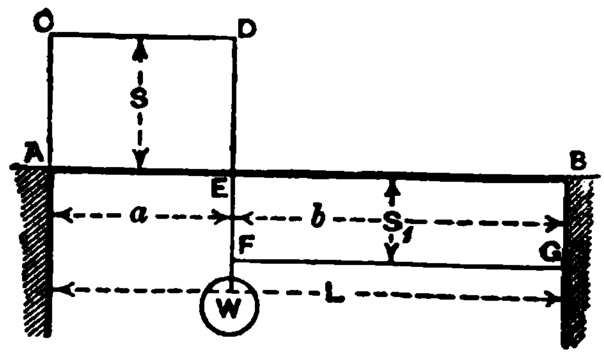
Supported at both ends, load out of centre.

Fig. 187.



Set off $M = \frac{Wab}{L}$, and join AC and BC.

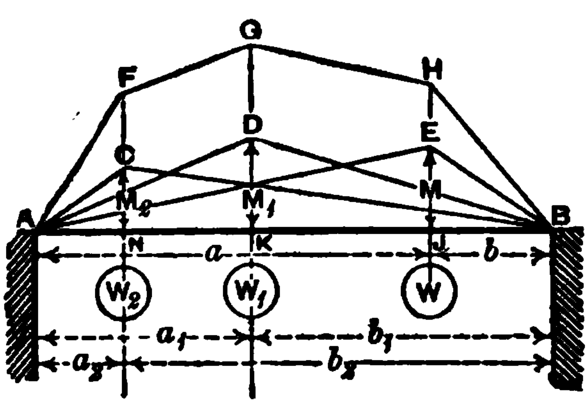
Fig. 188.



Set off $S = \frac{Wb}{L}$, and $S_1 = \frac{Wa}{L}$, and construct rectangles ACDE and EBGF.

Supported at both ends, unequally distributed loads.

Fig. 189.

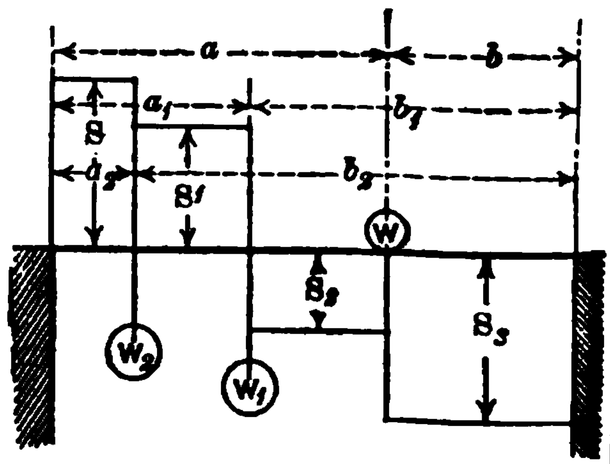


The bending moment at any point is equal to the sum of the bending moments produced at that point by each of the weights separately. Set off

$M = \frac{Wab}{L}$, $M_1 = \frac{W_1 a_1 b_1}{L}$, $M_2 = \frac{W_2 a_2 b_2}{L}$.

Then set up JH, KG, and NF, making the length for whole ordinates equal to the sum of the three ordinates at those points due to the several bending moments.

Fig. 190.



Set up

$$S = \frac{Wb + W_1 b_1 + W_2 b_2}{L},$$

$$S_1 = \frac{Wb + W_1 b_1 + W_2 b_2}{L} - W_2,$$

$$S_2 = \frac{Wb + W_1 b_1 + W_2 b_2}{L} - W_2 - W_1,$$

$$S_3 = \frac{Wb + W_1 b_1 + W_2 b_2}{L} - W_2 - W_1 -$$

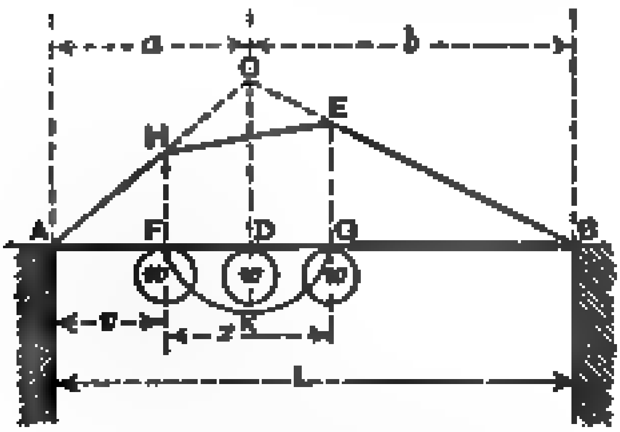
$$= \frac{Wa + W_1 a_1 + W_2 a_2}{L}.$$

TABLE OF GRAPHICAL BENDING MOMENTS, &c.—*cont.*

Bending Moments	Shearing Forces

Supported at both ends, and partial uniform load not extending to either support.

FIG. 191.



Set off CD at centre of load $=\dfrac{wzab}{L}$, and join AC and BC; at ends of z erect perpendiculars HF and EG, cutting AC and BC in H and E Join D and E, then on z draw the parabola FGK, whose middle ordinate equals $\dfrac{wz^2}{8}$.

FIG. 192.

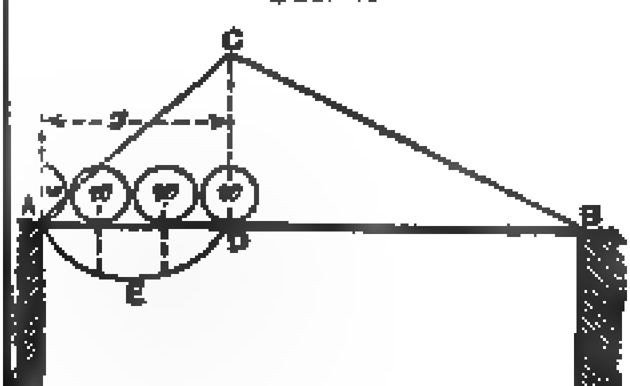
Set up $S = \dfrac{wz}{2L}(2L - 2v - z)$,

and $S_1 = \dfrac{wz}{2L}(2v + z)$,

and construct the diagram as in figure.

Supported at both ends, with partial uniform load extending to one support.

FIG. 192A.



Set up $CD = \dfrac{wz(2L - z)}{2L}$; then draw underneath the parabola AED, whose ordinate at centre $= \dfrac{wz^2}{8}$.

FIG. 193.

Set up S at $A = \dfrac{wz(2L - z)}{2L}$,

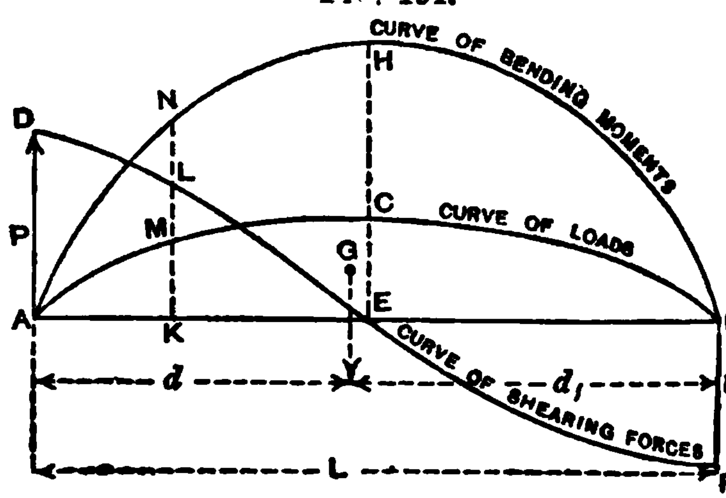
and set down $S_1 = \dfrac{wz^2}{2L}$,

and construct the diagram.

Beam supported at both ends and loaded continuously, but unevenly distributed. (Fig. 194.)

Curve of Load.—Set up weight of load per unit of length, say in tons per foot, at suitable points in the length of the beam; a curve ACB then drawn through the points thus found will form the curve of loads whose area will equal the total load on the beam in tons.

FIG. 194.



Supporting Pressures.—Find the distance of the centre of gravity G of the area of curve of loads from either support. Then if

W = total load, P and P_1 = supporting pressures at A and B respectively, d and d_1 = distances of G from A and B respectively.

$$\text{Then } PL = Wd_1, \text{ and } P = \frac{Wd_1}{L};$$

$$P_1L = Wd, \text{ and } P_1 = \frac{Wd}{L}.$$

Shearing Stresses.—Set up AD at A = P, and set down BF at B = P_1. To find the shearing stress at any point K, calculate the area of the curve of loads from A to the point K = area of AMK, and deduct this from the supporting force P, and set this up as an ordinate, KL, of the shearing curve. At E a point will be reached where the difference between the curve of loads and the supporting force P will be zero; this spot is termed the point of reverse racking. The differences from this point on will be negative, and are to be set down below the line AB.

Bending Moment.—This is found in a similar way to the shearing curve, only the area of the shearing curve between the end of the beam and the section, say at K, is equal to the bending moment at that point. That is, the area ADKL is equal to the bending moment at the point K, and is set up as an ordinate, KN, of the curve.

The maximum bending moment occurs at E, where the shearing force is zero, and is equal to the area ADE; the shearing stresses from this point on, being negative, have to be deducted. The part area of the load curve ACE is equal to the supporting force AD.

The part area of the load curve BCE is equal to the supporting force BF.

STRENGTH OF MATERIALS AND STRESSES IN SHIP'S STRUCTURE AND FITTINGS.

DEFINITIONS.

1. *Stress* is the mutual action between two parts of a body which preserves them in nearly the same relative position when acting upon by forces.

2. *Normal or direct stress* across a plane is the component force per unit area perpendicular to the plane. If the external forces tend to press the two portions together, the stress is termed *compressive*; if the two portions tend to separate, the stress is termed *tensile*.

3. *Shear or transverse stress* across a plane is the component force per unit area in a direction parallel to the plane.

4. *Strain* is the deformation of a body produced by stress.

5. *Longitudinal strain* is the extension produced in unit length. If negative it is a compression.

6. *Shear strain* is the relative rotation of particles produced stress. It is measured by the change of inclination of two lines in the plane of strain which were originally perpendicular.

7. *Strength* is the amount of stress a body can stand under certain assumed conditions.

8. *Ultimate strength* is the maximum stress that can be applied without rupture.

9. *Proof stress* is the maximum stress that a body can bear without injury, i.e. without a permanent change of properties.

10. *Proof load* is the load or total force producing the proof stress.

11. *Set* is permanent strain after stress is removed.

12. *Elastic limit* is the utmost stress or strain that can be given without inducing set (or, in practice, much set, since all stresses are found to cause a minute amount of set).

13. *Working load* is the maximum load or total force obtained under working conditions.

14. *Working strength* is the corresponding stress under working load.

15. *Stiffness* is a general term denoting the load or stress required to produce a certain strain.

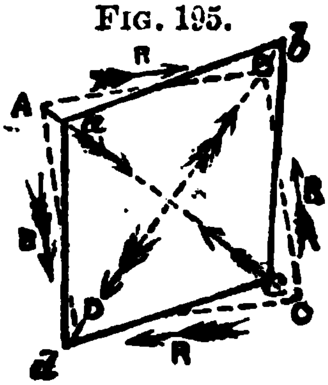
16. *Factor of safety* generally denotes the ratio in which the breaking load exceeds the working load.

ELASTIC COEFFICIENTS.

Within the elastic limit it is assumed that stress is proportional to strain. This is approximately correct for ductile materials, but brittle materials show a considerable variation from the law.

The Modulus of Elasticity, or Young's Modulus, denoted by E, denotes the quotient of the stress divided by the strain in a bar under longitudinal tension or compression. Thus in a bar of length L inches, which is stretched a inches by T tons per square inch, the strain is a/L, and $\text{E} = \text{TL}/a$. E may also be defined as the stress required to double the length of a bar, assuming the law of elasticity to hold good.

FIG. 195.



The coefficient of rigidity "C" is the shear stress divided by the shear strain. In Fig. 195 if the square ABCD is distorted by a shear stress R acting along the sides as shown into a rhombus $abcd$, the shear strain is equal to the amount by which the angle abc is less than a right angle, expressed in circular measure — say ϕ. Equally it = $\dfrac{2(\text{AC}-ac)}{\text{AC}} = \dfrac{2(bd-\text{BD})}{\text{BD}}$.

$$\text{Hence } \text{C} = \frac{\text{R}}{\phi} = \frac{\text{R}\,.\,\text{AC}}{2(\text{AC}-ac)} = \frac{\text{R}\,.\,\text{BD}}{2(bd-\text{BD})}$$

Poisson's ratio (σ). When a bar having free sides is extended under longitudinal stress, its sides contract so that the lateral strain is $-\dfrac{1}{\sigma}$ times the longitudinal strain. The contraction of area per cent is then $\dfrac{2}{\sigma}$ times the longitudinal strain per cent. The ratio σ is termed Poisson's ratio; it generally varies in value between 3 and 4. $\dfrac{1}{\sigma}$ is ·36 for brass, ·34 for copper, ·28 for iron, ·38 for lead, ·30 for steel, ·20 for zinc, ·5 for india-rubber, and 0 for cork.

Bulk Modulus (K) is the volumetric strain divided into the pressure producing it, assumed uniform. Thus under a uniform pressure p tons per square inch a body of volume V originally is reduced in volume to V-v. The volumetric strain is v/V; and the bulk modulus $\text{K} = p\text{V}/v$.

Note.—The linear contraction is one-third the volumetric strain; if the latter be 3 per cent, the former is 1 per cent.

These coefficients are interconnected by the following formulæ, so that when two of them are known, the others can be determined.

$$\text{E} = 2\text{C}\left(1+\frac{1}{\sigma}\right) = 3\text{K}\left(1-\frac{2}{\sigma}\right) = \frac{9\text{KC}}{\text{C}+3\text{K}}$$

$$\sigma = \frac{6\text{K}+2\text{C}}{3\text{K}-2\text{C}}$$

Note that E/C generally lies between 2·5 and $2\frac{2}{3}$; and E/K between $1\frac{1}{2}$ and 1. For values of E see p. 260. Average values for E and C are reproduced here:—

Material.	Tons per square inch.	
	E	C
Mild or high tensile steel ($\sigma = 3{\cdot}5$)	13,500	5,500
Riveted structural material as a whole	10,000	—
Wrought iron	12,500	5,000
Cast iron	7,500	3,000
Copper	6,500	2,500
Gun-metal	5,500	2,100

Note.—K for steel is 10,500; for water it is 130 or $\frac{1}{80}$ as much.

Factor of Safety.

The factor of safety, or the ratio of the ultimate load to the working load depends on the material and on the nature of the load. In certain materials, e.g. castings and timber, wide fluctuations in strength, caused by flaws or other defects, are observed; the factor for them is correspondingly higher than for rolled metals, which are more uniform in strength. With regard to the nature of the load, the factor is least in a 'dead' load, i.e. one which is either constant or varies slowly. For 'live' non-alternating loads it is nearly double that for a dead load, since the momentary stress, due to a load suddenly applied, may be nearly double that due to a steady load. For live alternating loads it is further increased, since the experiments of Wöhler and others show that stresses continually reversed even within the elastic limit lead to 'fatigue' and lower the elastic limit. Finally, under shock or impact very large stresses may be momentarily produced, though it appears that these do not generally damage the material to the same extent as do similar stresses acting during some appreciable time. The factor of safety due to such stresses is indeterminate generally, as it depends on the degree and nature of the impact.

Table of Factors of Safety. (Unwin.)

Material.	Dead Load.	Live and Varying Load.		Structure subject to Shock.
		Stress of one kind only.	Reversed Stresses.	
Cast iron . . .	4	6	10	15
Wrought iron and steel	3	5	8	12
Timber . . .	7	10	15	20

The following working stresses are deduced therefrom.

TABLE OF WORKING STRESSES.

Material.	Working Stress in Tons per square inch, under—		
	Dead Load.	Live Load without Reversed Stresses.	Live Load with Reversed Stresses.
Wrought iron . . .	(Board of T. 5) 7	4	2½
Mild steel	(Board of T. 6·5) 8	5	3
High tensile (H.T.) steel	10	6	4
„ (H.H.T.) steel	12	7	4½
Forged steel . . .	9	5½	3½
Rolled Naval brass .	7½	4½	3
Cast steel . . .	6½	4	2½
*Cast iron . . .	2¼	1½	1
„ special malleable	4½	3	2
Gun-metal . . .	3½	2½	1½
†Oak or Canada Elm .	·5	·35	·25
†Teak or Pitch Pine . .	·4	·25	·2
†Fir or Mahogany . .	·3	·2	·15

* For tension only. Under compressive stress multiply by two.
† Spars or timber subjected to bending may safely receive working stresses up to 1½ times those given in the table.

STRESS DUE TO BENDING.

Let M = bending moment in inch tons.
I = moment of inertia of section about neutral axis in (inches)^4.
p = tensile stress in tons per square inch at any point P in section.
y = distance of P from the neutral axis in inches.
ρ = radius of curvature in inches to which beam is bent along the neutral surface.
E = Young's Modulus (modulus of elasticity) in tons per square inch.

Then $\frac{p}{y} = \frac{M}{I} = \frac{E}{\rho}$ if beam is originally straight, and

$\frac{p}{y} = \frac{M}{I} = E\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right)$, approximately, if beam has originally a radius of curvature ρ_0.

If the beam be very broad in relation to its depth, as, for instance, a thin flat plate, change E to $\sigma^2 E/(\sigma^2 - 1)$, or about $1 \cdot 1$ E for steel, σ being Poisson's ratio.

Note.—The neutral surface is that surface which is u
strained when the beam is bent. It intersects each secti
of the beam at its *neutral axis* ; this is a straight line passi
through the centre of gravity of the section, and perpendicul
to the plane of bending.

When y is the greatest distance of any part of the secti
from the neutral axis, p, which is equal to $\frac{My}{I}$, is the maximu
stress at that section. Also $\frac{I}{y}p$ is equal to the bendi
moment M, so that it is the moment of resistance of t
beam. $\frac{I}{y}$ is then the moment of resistance corresponding
unit stress, and is termed the *modulus of the section.*

Then, Stress = Bending Moment ÷ Modulus of Section.

Moment of Inertia.

For methods of calculation the moment of inertia
various sections, etc., see pp. 69-75.

The moments of inertia and resistance of various sectio
are given in the tables below. (Moment of resistance =
× modulus of section = pI/y.)

Table of Moments of Inertia and Resistance of Various Sections.

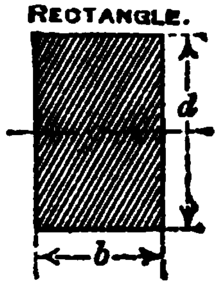
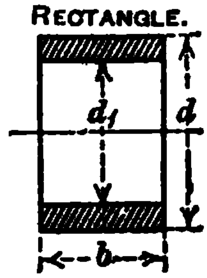
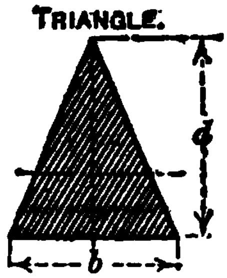
Form of Section	Moment of Inertia through Centre of Gravity	Moment of Resistance =M
RECTANGLE. 	$\frac{bd^3}{12}$	$p\frac{bd^2}{6}$
RECTANGLE. 	$\frac{b}{12}\left(d^3-d_1^3\right)$	$p\left\{\frac{b}{6d}\left(d^3-d_1^3\right)\right\}$
TRIANGLE. 	$\frac{bd^3}{36}$	$p\frac{bd^2}{24}$

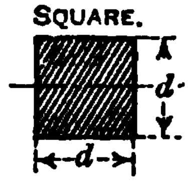
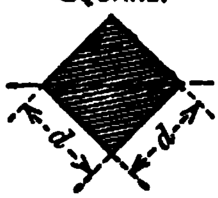
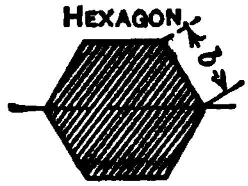
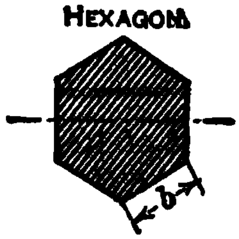
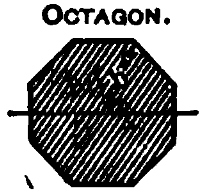
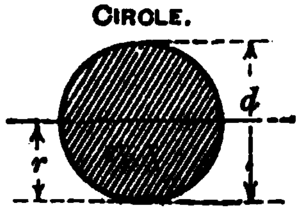
Table of Moments of Inertia, &c.—*cont.*		
Form of Section	**Moment of Inertia through Centre of Gravity**	**Moment of Resistance $=$ M**
SQUARE. 	$\frac{d^4}{12}$	$p\frac{d^3}{6}$
SQUARE. 	$\frac{d^4}{12}$	$\cdot118pd^3$
HEXAGON. 	$\frac{5}{16}b^4\sqrt{3}$ $=\cdot5413b^4$	$\frac{5}{8}pb^3=\cdot625pb^3$
HEXAGON. 	$\frac{5}{16}b^4\sqrt{3}$ $=\cdot5413b^4$	$\frac{5}{16}pb^3\sqrt{3}=\cdot5413pb^3$
OCTAGON. 	$\frac{1+2\sqrt{2}}{6}b^4$ $=\cdot638b^4$	$\cdot6906pb^3$
Regular polygon with n sides. $b=$side. $r=$radius of circumscribed circle. $a=$area $=\frac{nr^2}{2}\sin.\frac{2\pi}{n}$.	$\frac{a}{12}\left(3r^2-\frac{b^2}{2}\right)$	$p\frac{ra}{4}$
CIRCLE. 	$\frac{\pi d^4}{64}=\cdot0491d^4$ $=\frac{\pi r^4}{4}=\cdot7854r^4$	$p\frac{\pi d^3}{32}=\cdot0982pd^3$ $=p\frac{\pi r^3}{4}=\cdot7854pr^3$

TABLE OF MOMENTS OF INERTIA, &c.—*cont.*

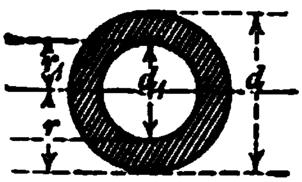
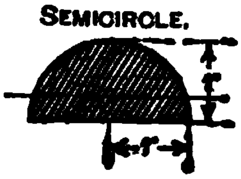
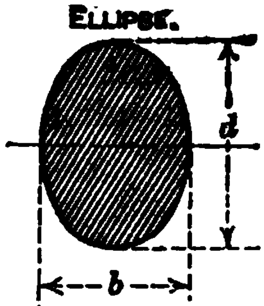
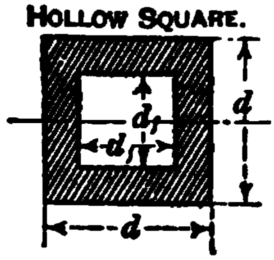
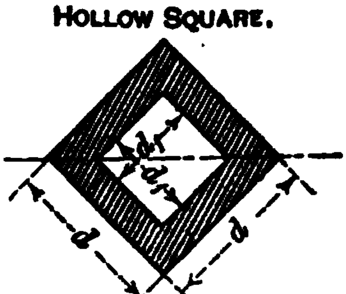
Form of Section	Moment of Inertia through Centre of Gravity	Moment of Resistance $=$M
HOLLOW CIRCLE. 	$\frac{\pi}{64}(d^4-d_1^4)$ $=\frac{\pi}{4}(r^4-r_1^4)$	$\frac{\pi}{32}\left(\frac{d^4-d_1^4}{d}\right)p$ $\frac{\pi}{4}\left(\frac{r^4-r_1^4}{r}\right)p$
SEMICIRCLE. 	$\cdot110d^4$	$\cdot19pr^3$
HOLLOW SEMICIRCLE. 	$\cdot110(r^4-r_1^4)$ $-\frac{\cdot283r^2r_1^2(r-r_1)}{r+r_1}$	$\frac{pI}{y}$
ELLIPSE. 	$\frac{\pi bd^3}{64}=\cdot0491bd^3$	$\frac{\pi bd^2}{32}p=\cdot0982pbd^2$
HOLLOW SQUARE. 	$\frac{d^4-d_1^4}{12}$	$\frac{1}{6}\left(\frac{d^4-d_1^4}{d}\right)$
HOLLOW SQUARE. 	$\frac{d^4-d_1^4}{12}$	$p\left(\frac{d^4-d_1^4}{12d}\right)\sqrt{2}$ $=\cdot1178\left(\frac{d^4-d_1^4}{d}\right)p$

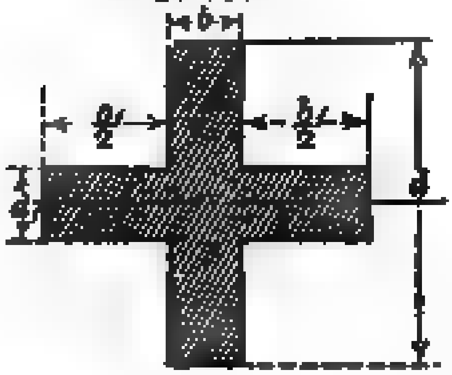
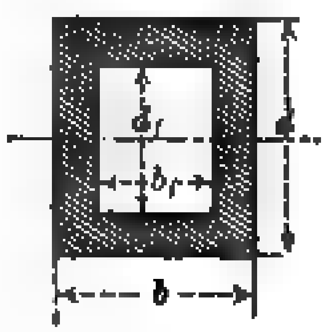
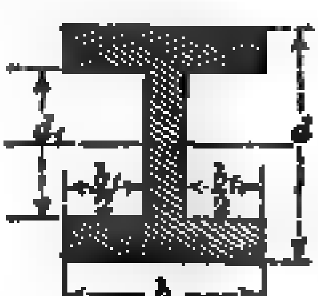
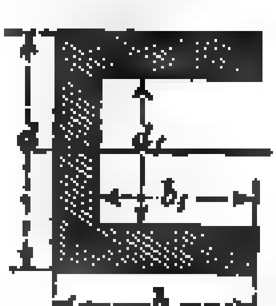
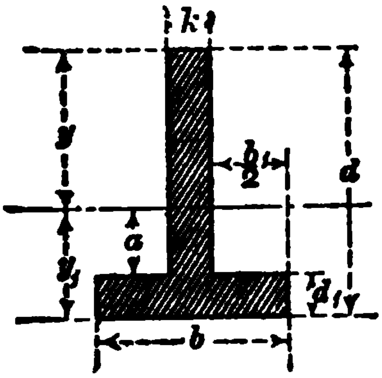
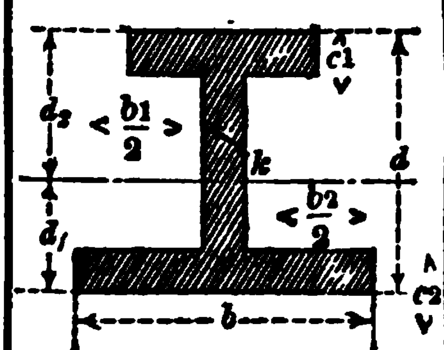
TABLE OF MOMENTS OF INERTIA, &c.—*cont.*		
Form of Section	Moment of Inertia through Centre of Gravity	Moment of Resistance = M
CROSS. 	$\dfrac{bd^3 + b_1 d_1^3}{12}$	$p\dfrac{bd^3 + b_1 d_1^3}{6d}$
	Note.—The moment of inertia of a hollow section about any axis is equal to the moment of inertia of the whole section taken as solid about that axis and then deducting the moment of the hollow part from it about the same axis.	
  	$\dfrac{bd^3 - b_1 d_1^3}{12}$	$p\left(\dfrac{bd^3 - b_1 d_1^3}{6d}\right)$

TABLE OF MOMENTS OF INERTIA, &c.—*cont.*

Form of Section.	Moment of Inertia through Centre of Gravity.	Moment of Resistance = M
	$\frac{kd^3}{12}\left\{1+\frac{3b_1d_1}{b_1d_1+kd}\right\}$	$p\frac{I}{y}$; where $y_1=\frac{d}{2}\cdot\frac{kd}{b_1d_1+kd}$ $y=\frac{d}{2}\cdot\frac{2b_1d_1+kd}{b_1d_1+kd}$
	$\frac{1}{12}kd^3+\frac{1}{4}\frac{d^2}{A}\left\{(b_1c_1+b_2c_2)kd+4b_1c_1b_2c_2\right\}$ where $A=\text{area}=b_1c_1+b_2c_2+kd$ $d_1=d(2b_1c_1+kd)/2A$ $d_2=d(2b_2c_2+kd)/2A$	

The formulæ for the last two figures are approximate the thickness of flanges and web being assumed com paratively small.

Note.—From the above figures the moments of inertia an resistance can be reduced very approximately for many sectiona materials, including angle bars, T bars, I bars, Z's, and channels See also pp. 241-254.

Example.—A cast-iron bar whose section is of the form give last in the above list, and where $d=12''$, $c_1=c_2=1''$, $k=1''$, $b_1=3''$ $b_2=8''$, is placed on supports 25 feet apart. Find the limitin distributed live load that it can support.

From the formula $I=495$ (inches)^4, $d_1=5\cdot57''$, $d_2=6\cdot48''$ Since the upper flange is in compression, and therefore ampl strong for cast-iron, y should be taken as $5\cdot57''$ for the lowe flange in tension. Also $p=1\cdot5$. Hence moment of resistanc $=\frac{pI}{y}=\frac{1\cdot5\times495}{5\cdot57}=133$ inch-tons.

Bending moment $=\frac{Wl}{8}=\frac{W\times25\times12}{8}$ inch-tons when W i the load. Hence load in tons $=\frac{133\times8}{25\times12}=3\cdot55$.

Table of Moments of Inertia and Moduli of Sections for Circular Sections

Diameter in Inches	Moment of Inertia	Modulus of Section or I/y.	Diameter in Inches	Moment of Inertia	Modulus of Section or I/y.	Diameter in Inches	Moment of Inertia	Modulus of Section or I/y.
1	0·0491	0·0982	35	73662	4209	69	1112660	32251
2	0·7854	0·7854	36	82448	4580	70	1178588	33674
3	3·976	2·651	37	91998	4973	71	1247393	35138
4	12·57	6·283	38	102354	5387	72	1319167	36644
5	30·68	12·27	39	113561	5824	73	1393995	38192
6	63·62	21·21	40	125664	6283	74	1471963	39783
7	117·9	33·67	41	138709	6766	75	1553156	41417
8	201·1	50·27	42	152745	7274	76	1637662	43096
9	322·1	71·57	43	167820	7806	77	1725571	44820
10	490·9	98·17	44	183984	8363	78	1816972	46589
11	718·7	130·7	45	201289	8946	79	1911967	48404
12	1018	169·6	46	219787	9556	80	2010619	50265
13	1402	215·7	47	239531	10193	81	2113051	52174
14	1886	269·4	48	260576	10857	82	2219347	54130
15	2485	331·3	49	282979	11550	83	2329605	56135
16	3217	402·1	50	306796	12272	84	2443920	58189
17	4100	482·3	51	332086	13023	85	2562392	60292
18	5153	572·6	52	358908	13804	86	2685120	62445
19	6397	673·4	53	387323	14616	87	2812205	64648
20	7854	785·4	54	417393	15459	88	2943748	66903
21	9547	909·2	55	449180	16334	89	3079853	69210
22	11499	1045	56	482750	17241	90	3220623	71569
23	13737	1194	57	518166	18181	91	3366165	73982
24	16286	1357	58	555497	19155	92	3516586	76448
25	19175	1534	59	594810	20163	93	3671992	78968
26	22432	1726	60	636172	21206	94	3832492	81542
27	26087	1932	61	679651	22284	95	3998198	84173
28	30172	2155	62	725332	23398	96	4169220	86859
29	34719	2394	63	773272	24548	97	4345671	89601
30	39761	2651	64	823550	25736	98	4527664	92401
31	45333	2925	65	876240	26961	99	4715315	95259
32	51472	3217	66	931420	28225	100	4908738	98175
33	58214	3528	67	989166	29527			
34	65597	3859	68	1049556	30869			

Note.—For shafts subjected to torsion, the torsional inertia and modulus are found by doubling their values in the above table.

Table of Moments of Inertia and Moduli of Sections ($I \div y$) for Hollow Tubular Sections.

External Diameter in Inches	Thickness in Inches								
	1·2	1·5	1·8	2·0	2·2	2·5	2·8	3·0	3·5
10	327·1 65·42	373·0 74·60	408·5 81·70	427·3 85·45					
11	405·2 81·85	517·6 94·11	571·5 103·9	600·8 109·2	625·6 113·8				
12	601·0 100·2	695·8 116·0	773·5 128·9	816·8 136·1	854·1 142·4	900·0 150·0			
13	782·3 120·3	911·1 140·2	1019 156·8	1080 166·1	1134 174·4	1201 184·8			
14	996·9 142·4	1167 166·7	1311 187·4	1395 199·3	1469 209·9	1564 223·4			
15	1248 166·4	1467 195·6	1656 220·8	1766 235·5	1866 248·8	1994 265·9	2102 280·2		
16	1538 192·2	1815 226·9	2056 257·1	2199 274·9	2329 291·1	2498 312·3	2643 330·3		
17	1869 219·9	2214 260·5	2517 296·1	2698 317·4	2863 336·8	3082 362·6	3271 384·8	381 397·8	
18	2246 249·5	2668 296·4	3042 338·0	3267 363·0	3475 386·1	3751 416·8	3992 443·6	4135 459·5	
19		3180 334·8	3636 382·8	3912 411·8	4168 438·7	4511 474·9	4814 506·8	4995 525·8	
20		3754 375·4	4303 430·3	4637 463·7	4948 494·8	5369 536·9	5743 574·3	5968 596·8	6452 645·
22·5			6319 561·7	6831 607·2	7311 650·0	7977 709·0	8575 762·3	8942 794·9	9747 866·
25			8880 710·4	9628 770·2	10334 827·0	11320 905·7	12222 977·7	12778 1022	14022 1122
27·5				13602 952·9	14095 1025	15493 1127	16782 1221	17585 1279	19397 1411
30				17327 1155	18676 1246	20586 1372	22359 1491	23472 1565	26021 1735
32·5				22377 1377	24157 1487	26688 1643	29058 1788	30554 1880	34005 2093
35				28325 1619	30619 1750	33896 1937	36983 2114	38938 2225	43484 2485
37·5				35245 1880	38145 2035	42301 2256	46237 2466	48736 2599	54588 2912
40				43210 2161	46818 2341	51996 2600	56917 2846	60058 3003	67440 3372

Note.—The first figures given are the moments of inertia, and the second the moduli of sections ($I \div y$).

Note.—For shafts subjected to torsion, the torsional inertia and moduli are found by doubling their values in the above table.

Continuous Beams.

Distribution of load on each equidistant level support of a continuous beam uniformly loaded.

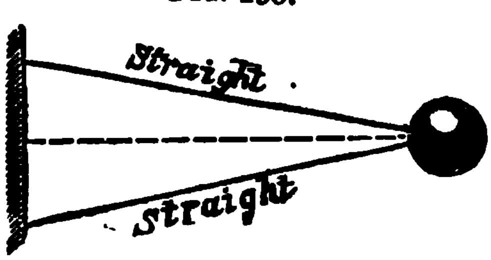
Divide the load on each span by the dividing factor in the table below; then multiply by the corresponding figure under 'Reactions at props'.

Number of Spans.	Dividing Factors.	Reactions at Props.					
2	8	3	10	3			
3	10	4	11	11	4		
4	28	11	32	26	32	11	
5	38	15	43	37	37	43	15
6	104	41	118	108	106	108	etc.
7	142	56	161	137	143	143	etc.
8	388	152	440	374	392	386	etc.
9	530	209	601	511	535	529	etc.
Any large number.	1	·394	1·134	·964	1·01	about 1	etc.

Table of Beams of Equal Strength throughout their Length.

Note.—The sections are in all cases supposed to be rectangular.

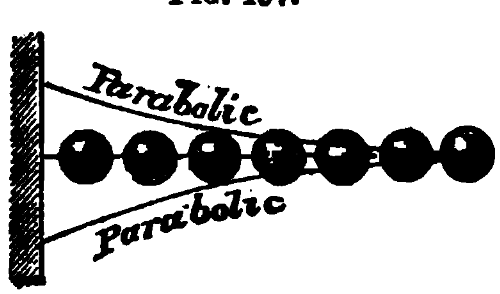
Fig. 196.



Depth equal throughout.

Breadth proportional to distance from loaded end.

Fig. 197.



Depth equal throughout.

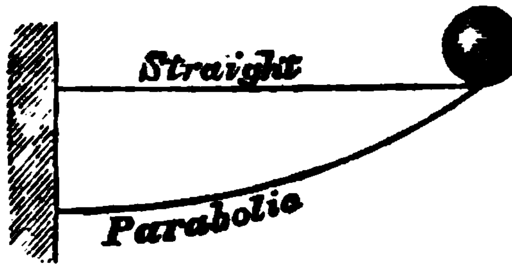
Breadth proportional to square of distance from unsupported end.

TABLE OF BEAMS OF EQUAL STRENGTH THROUGHOUT THEIR LENGTH (concluded).

Breadth equal throughout.

Depth proportional to square root of distance from loaded end.

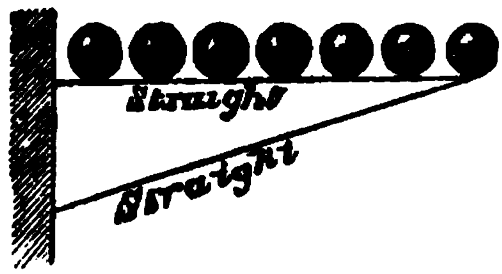
FIG. 198.



Breadth equal throughout.

Depth proportional to distance from unsupported end.

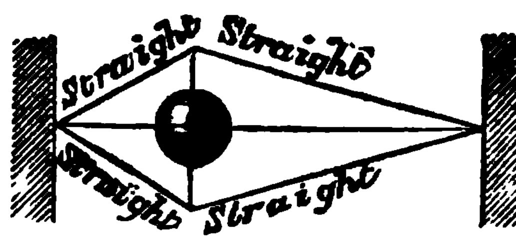
FIG. 199.



Depth equal throughout.

Breadth proportional to distance from nearest point of support.

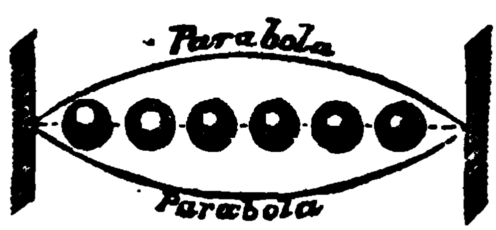
FIG. 200.



Depth equal throughout.

Breadth proportional to product of distance from both points of support.

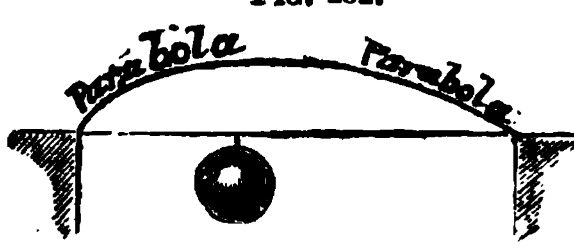
FIG. 201.



Breadth equal throughout.

Depth proportional to the square root of the distance from the nearest point of support.

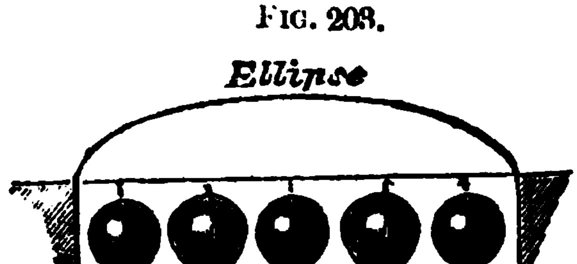
FIG. 202.



Breadth equal throughout.

Depth proportional to the square root of the product of distance from both points of support.

FIG. 203.



Distribution of 2 or 3 supports for minimum Bending Moment.—Let W be total load assumed uniformly distributed and l the total length of beam.

For 2 supports, place each ·207 l from end; B.M. (maximum) at supports and at middle is ·0215 Wl.

For 3 supports at the same level place one at middle, and the others ·145l from end; BM (maximum) at supports is ·0102 Wl. If the level of the central prop is adjusted so that it supports W/3, and if the other supports are then ·13 l from end, BM is only ·0085 Wl.

Bending Moments and Deflections of Beams.

L = length or span of beam in inches.
I = moment of inertia in (inches)^4, of greatest cross section if not uniform.
W = total load on beam in tons.
E = Young's modulus (pp. 260, 311) in tons per square inch.
D = maximum deflection in inches.
M_0 = bending moment at end.
M = maximum bending moment at or near the middle.

Then $D = \frac{K_1 WL^3}{EI}$; $M_0 = K_2 WL$; $M = K_3 WL$ where K_1, K_2, K_3 have the values in the table on p. 323.

Strength of Bulkheads under Water Pressure.

It is assumed that the bulkhead is sufficiently wide for its central portions to be uninfluenced by the connexions at the sides (otherwise a narrow deep bulkhead, horizontally stiffened, may be treated as a series of horizontal girders uniformly loaded). For stresses on the plating between the stiffeners see 'Stress in flat plating', p. 325.

Consider the stiffener together with a strip of the adjacent plating as forming a girder; calculate the position of C.G. of its section, the moment of inertia I about an axis through G parallel to the bulkhead, and the modulus I/y. The width of the strip of plating should not exceed the stiffener spacing; neither should plating extending more than fifteen times its thickness beyond the line (or outside lines) of stiffener rivets be included.

Let a = head of water in feet above top of bulkhead (if negative, take $a = 0$).
h = height of bulkhead in feet.
b = stiffener spacing in inches.
I = moment of inertia of section, including one stiffener and plating of width b, in inch units.
E = modulus of elasticity in tons per square inch.

No.	Description of beam, load, and support.	K_1	K_2	K_3	Remarks.
1	Uniform cantilever, loaded at free end	$\frac{1}{3}$	1		
2	Cantilever of uniform strength and depth, loaded at free end	$\frac{1}{2}$	1	—	
3	Cantilever of uniform strength and breadth, ,, ,,	$\frac{2}{3}$	1		
4	Uniform cantilever, uniformly loaded	$\frac{1}{8}$	$\frac{1}{2}$	—	
5	Cantilever … loaded	$\frac{1}{4}$	$\frac{1}{2}$	—	
6	Cantilever ,,	$\frac{1}{3}$	$\frac{1}{2}$	—	
7	Uniform cantilever, uniformly loaded, propped at free end	$\frac{1}{185}$	$\frac{1}{8}$	$\frac{9}{128}$	Max. M at $\frac{3}{8}$ L, and deflection at $\frac{3}{8}$ L from free end. Prop supports $\frac{3}{8}$ W.
8	Uniform beam, supported both ends, loaded at centre	$\frac{1}{48}$	—	$\frac{1}{4}$	
9	… and depth, supported both …	$\frac{1}{32}$	—	$\frac{1}{4}$	
10	Beam of uniform strength and breadth, supported both ends, loaded at centre	$\frac{1}{16}$	—	$\frac{1}{4}$	
11	Uniform beam, supported both ends, loaded uniformly	$\frac{5}{384}$	—	$\frac{1}{8}$	
12	… depth, supported both ends, …	$\frac{1}{64}$	—	$\frac{1}{8}$	
13	Beam of uniform strength and breadth, supported both ends, loaded uniformly	$\frac{1}{32}\left(\frac{\pi}{2}-1\right)$ or $\frac{1}{56\cdot1}$	—	$\frac{1}{8}$	
14	Uniform beam, fixed both ends, loaded at centre	$\frac{1}{192}$	$\frac{1}{8}$	$\frac{1}{8}$	
15	Uniform beam, fixed both ends, loaded distance a from end A, b from end B, where $a+b=L$, $a>b$.	$\frac{2a^3b^2}{3(3a+b)^2L^3}$	$\frac{ab^2}{L^2}$ at A $\frac{a^2b}{L^2}$ at B	$\frac{ab}{2L^2}$ at load.	Max. defl. at $\frac{2aL}{3a+b}$ from A.
16	As above, but freely supported both ends	$\frac{b(a^2+2ab)^{\frac{3}{2}}}{9\sqrt{3}L^4}$	—	$\frac{ab}{L^2}$ at load.	Max. defl. at $\sqrt{\frac{a^2+2ab}{3}}$ from A.
17	Uniform beam, fixed both ends, loaded uniformly	$\frac{1}{384}$	$\frac{1}{12}$	$\frac{1}{24}$	
18	Uniform beam, fixed at one end, freely supported at the other end, loaded uniformly	The same as No. 7.			
19	Uniform beam, uniformly loaded, ends partly fixed so as to minimize bending moment	$\frac{1}{192}$	$\frac{1}{16}$	$\frac{1}{16}$	

Then the pressure on top and bottom boundary angles, the bending moments, and the deflections are obtained from the following table :—

For width 'b'.	Stiffeners unbracketed and assumed 'free' at top and bottom.	Stiffeners well bracketed and assumed fixed in direction at ends.
Total pressure on plating in tons	$\frac{bh}{840}(2a+h)$	$\frac{bh}{840}(2a+h)$
Support at top boundary in tons	$\frac{bh}{840}\left(a+\frac{h}{3}\right)$	$\frac{bh}{840}\left(a+\frac{3h}{10}\right)$
Support at bottom boundary in tons . . .	$\frac{bh}{840}\left(a+\frac{2h}{3}\right)$	$\frac{bh}{840}\left(a+\frac{7h}{10}\right)$
Bending moment at top in inch-tons . . .	—	$\frac{bh^2}{1050}\left(\frac{5a}{2}+h\right)$
Bending moment at mid-depth in inch-tons . .	$\frac{bh^2}{560}(2a+h)$	$\frac{bh^2}{1680}(2a+h)$
Bending moment at bottom in inch-tons . .	—	$\frac{bh^2}{700}\left(\frac{5a}{8}+h\right)$
Deflection at mid-depth in inches	$\frac{3}{112}\frac{bh^4(2a+h)}{EI}$	$\frac{3}{560}\frac{bh^4(2a+h)}{EI}$
Deflection for steel (E = 13,500 tons/in.^{2}) . .	$\frac{bh^4(2a+h)}{504{,}000\,I}$	$\frac{bh^4(2a+h)}{2{,}520{,}000\,I}$
Depth of position for max. B.M. below top } when	·58 h	·55 h
" " " deflection " } $a=0$	·52 h	·52 h

Note.—From the last two lines it is evident that the bending moment and deflection at mid-depth may be assumed to be the maximum without appreciable error. The stiffener stresses may be deduced from these bending moments; the boundary bar riveting from the top and bottom supports; and the top and bottom stiffener brackets may be roughly constructed to take the corresponding bending moments. The deflection and B.M. at mid-depth are the same as if the total pressure was uniformly distributed. Calculated stiffener stresses up to 18 or 20 tons per square inch are permissible.

Example.—A bulkhead is stiffened with channel bars 12″ × 4″ × 4″ × ·50″, spaced 2′ 6″ apart, the mean thickness of plating being ·40″. Find the stresses, etc., assuming stiffeners unbracketed; the depth of the bulkhead is 20 feet, and the head of water 5 feet at the top.

Consider a strip consisting of stiffener and plating. The width of the latter is limited to 30″ (stiffener spacing) and also to 12″ (fifteen times the thickness each side); the smaller figure must be taken. Find I and y, taking trial neutral axis through centre of stiffener.

Item.	Area in sq.-in. (A).	a from axis.	Moment.	Moment of Inertia.	Depth of flange (d).	$\frac{1}{12}Ad^2$.
Web of channel .	6·0	—	—	—	12	72
Flanges of channel	1·75	+5·75	+10·1	58	—	—
	1·75	−5·75	−10·1	58	—	—
Bulkhead plating .	4·8	6·2	+29·7	184	—	—
	14·3		29·7	300		72
				72		
				372 = M.I. about assumed axis.		

Real neutral axis $= \dfrac{29\cdot7}{14\cdot3} = 2\cdot08''$ from assumed axis.

M.I. about real axis $= 372 - 14\cdot3 \times (2\cdot08)^2 = 310$. $y = 6 + 2\cdot08 = 8\cdot08$. Modulus $I/y = 372/8\cdot08 = 46\cdot1$. Maximum B.M. $= \dfrac{bh^2}{560}(2a+h) = \dfrac{30\times400}{560}(20+10) = 643$ inch-tons. Stress in stiffener $= My/I = 643/46\cdot1 = 14$ tons per square inch. Maximum deflection $= \dfrac{30\times20^4\times30}{504{,}000\times372} = \cdot77$ inches.

Stress in Flat Plating under Water Pressure.

h = head of salt water in feet.
t = thickness of plate in inches.
a = one-half the breadth between supports in feet.
f = maximum stress in material in tons per square inch.
δ = central deflection in inches (Young's modulus assumed to be 13,500 tons per square inch).

In long plates whose edges are free to angle put

$$A = \frac{1}{307{,}000}h^2\left(\frac{a}{t}\right)^8; \text{ then } f = \frac{1}{12\cdot8}Bha^2/t^2 \text{ and } \delta = \frac{1}{1{,}440}Cha^4/t^3,$$

when B and C are read off opposite A in the table on p. 326.*

Similarly, if the edges are fixed or continuous, put

$$D = \frac{1}{7\cdot82\times10^6}h^2\left(\frac{a}{t}\right)^8; \text{ then } f = \frac{1}{19\cdot2}Eha^2/t^2 \text{ and } \delta = \frac{1}{7{,}200}Fha^4/t^3,$$

when E and F are read off opposite D in the table on p. 326.*

* Extracted from Trans. I.N.A., 1902; paper by Mons. Boobnoff.

A.	B.	C.	D.	E.	F.
·304	·991	·908	·208	1·012	·980
1·974	·839	·711	·988	·997	·926
10·12	·633	·496	1·82	·976	·877
27·4	·512	·380	2·88	·954	·834
57·4	·432	·308	4·12	·933	·794
103·2	·376	·259	5·56	·912	·758
167·8	·334	·223	7·21	·893	·725
255	·302	·196	9·09	·874	·696
510	·255	·158	11·19	·857	·668
894	·222	·132	23·7	·701	·404
1653	·191	·108	150	·464	·262

If the plate is stiff, so that the deflection is slight, do not calculate A or D, but take B = C = E = F = 1.

If the plate is so flexible that the resistance to flexure is negligible compared with the hoop tension, f being uniform,

$$f^3 = \frac{1}{78\cdot5} h^2 a^2/t^2\,; \quad \delta^3 = \frac{1}{4{,}380} \cdot ha^4/t.$$

If however the edges are allowed to approach, as in the bottom of a box, or if the plate is initially curved, δ being the final deflection, $f = ha^2/70\,\delta t$; if initially flat the sides approach by $\delta^2/9a$ in.

If the length of the plate be $2l$ feet, and its ends are supported like the sides, substitute $al/\sqrt{a^2 + l^2}$ for a in the above formulæ.

A high nominal stress, *e.g.*, 18 tons per square inch, is frequently adopted in bulkhead and even shell plating.

Diameter of a Davit.

Let d = diameter in inches.
H = height of davit above uppermost support in feet.
S = overhang in feet.
W = maximum load in tons on each davit.
$d^3 = 30$ W (S + $\frac{1}{4}$ H) for wrought iron, allowing 4 tons/inch^2.
$d^3 = 22$ W (S + $\frac{1}{4}$ H) for forged steel, allowing $5\frac{1}{2}$ tons/inch^2.

Lloyd's Rule.—(*a*) For boats and davits of ordinary proportions,

$$d = \tfrac{1}{5}\ \text{length of boat in feet.}$$

(*b*) Otherwise, d^3 = L.B.D. ($\frac{1}{3}$H + S)/40, where L, B, and D are the principal dimensions of the boat in feet.

Board of Trade Rule.—d^3 = L.B.D. ($\frac{1}{4}$ H + S)/c, where c = 21·5 for iron and 26 for steel.

Unsymmetrical Beams.

If the beam or loading is unsymmetrical resolve the B.M. into components in the planes of the principal axes of inertia of the section. Treat each component separately and

find the stress and deflection due to it. The final stress is the sum (or difference, if of opposite signs) of the two component stresses at the same point. The final deflection is compounded of the two components.

In pp. 241 to 254, particulars of the principal moments of inertia, etc., are given for the British Standard Sections.

If lateral deflection is prevented, as in a beam connected to deck plating, the section can be treated as if symmetrical, and the stresses and deflection found by the ordinary method, using the moment of inertia about an axis perpendicular to the plane of bending.

Example. — Find the greatest stress and the deflection of a standard angle bulb beam $4'' \times 2\frac{1}{2}'' \times \cdot 3''$, resting on supports 10 feet apart, carrying one ton uniformly distributed (*a*) if free laterally, (*b*) if lateral movement is prevented.

Maximum bending moment is 15 inch-tons. Angle $\alpha = 14\frac{3}{4}°$.

(*a*) Least moment of inertia $= 2\cdot 17 \times (\cdot 548)^2 = \cdot 652$.

Greatest moment of inertia $= 4\cdot 461 + \cdot 915 - \cdot 652 = 4\cdot 724$ (see p. 241).

In plane of minor axis, $\text{M}/\text{I} = 15 \cos \alpha / 4\cdot 724 = 3\cdot 07$.

In plane of major axis, $\text{M}/\text{I} = 15 \sin \alpha / \ \cdot 652 = 5\cdot 86$.

The greatest compressive stress is evidently at the corner of the bulb, which is $1\cdot 46''$ above the greater axis and $\cdot 98''$ from the least axis.

Stress due to bending in plane of minor axis $= 3\cdot 07 \times 1\cdot 46 = 4\cdot 48$ tons/inch^2.

Stress due to bending in plane of major axis $= 5\cdot 86 \times \cdot 98 = 5\cdot 75$ tons/inch^2.

Maximum compressive stress is $4\cdot 48 + 5\cdot 75 = 10\cdot 23$ tons per square inch. Similarly the maximum tension is found to be at a point near the bulb, and it is equal to $10\cdot 86$ tons per square inch.

$$\text{Deflection in plane of minor axis} = \frac{5}{384}\frac{wl^4}{\text{EI}} = \frac{5}{48}\frac{\text{M}l^2}{\text{EI}}$$

$$= \frac{5 \times 3\cdot 07 \times 120 \times 120}{48 \times 13{,}500} = \cdot 34 \text{ inch.}$$

Deflection in plane of major axis is similarly $\cdot 65$ inch.

Net deflection is $\sqrt{(\cdot 34)^2 + (\cdot 65)^2}$ or $\cdot 73$ inch, in a direction $\tan^{-1} 65/34$ or $59°$ with the minor axis, that is $44°$ with the vertical, towards the right as drawn in fig. 156.

(*b*) Section modulus (I/y) about horizontal axis is $1\cdot 907$.

Greatest stress $= 15/1\cdot 907 = 7\cdot 87$ tons per square inch.

This is at the bottom where y is greatest.

At the top $y = 1\cdot 66$. $\text{I} = 4\cdot 46$.

Maximum compressive stress $= 15 \times 1\cdot 66/4\cdot 46 = 5\cdot 59$ tons per square inch.

$$\text{Deflection (vertical)} = \frac{5 \times 15 \times 120 \times 120}{48 \times 13{,}500 \times 4\cdot 46} = \cdot 37 \text{ inch.}$$

Strength of Fly-wheels and Pulleys.

Stress = density × (linear velocity of rim)$^2/g$.

For cast-iron wheels, stress in tons per square inch = (speed in thousands of feet per minute)$^2 \div 83$. In pulleys the maximum working stress is about ·45 ton/inch^2, the corresponding velocity being about 6,000 feet per minute. In solid fly-wheels, working stress is ·28 ton/inch^2, velocity 4,800 feet/min., although the higher stress given for pulleys is sometimes admissible. In built-up fly-wheels, stress is ·1 ton/inch^2, velocity 3,000 feet/min. A cast-iron fly-wheel bursts at about 25,000 feet per minute.

Pillars.*

Let W = breaking or crippling load in tons on pillar.
A = sectional area of material in square inches.
l = length of pillar in inches, if round-ended †; = $\frac{1}{2}$ length of pillar if square-ended or fixed at ends; = $\frac{1}{\sqrt{2}}$ length if fixed at one end.
ρ = least radius of gyration of cross section in inches.
or $A\rho^2$ = least moment of inertia of cross section in (inches)^4.
f, a = coefficients depending on the material.
t = minimum thickness of material, if hollow, in inches.
N = coefficient for a hollow pillar depending on shape of section = 500 for a circle, 600 for a square, 1,200 for a cross, 800 for an equilateral triangle, 700 for an I bar. In a solid pillar put N = 0.

For very long pillars where l/ρ is greater than 150 (*i.e.* if l is more than about 40 diameters, if circular) $\frac{W}{A} = \pi^2 E \Big/ \left(\frac{N\rho}{t} + \frac{l^2}{\rho^2}\right)$, where E is the modulus of elasticity, $= 130{,}000 \div \left(\frac{N\rho}{t} + \frac{l^2}{\rho^2}\right)$ for mild steel.

For long circular solid pillars of length L in *feet*, diameter d in *inches* the collapsing load is $45d^4/L^2$ for iron or steel, $2d^4/L^2$ for oak, $2\frac{1}{2}d^4/L^2$ for pine. If hollow the load is $kt^2/(1+6{\cdot}5\frac{L^2 t}{d^3})$, where k = 2,300 for steel, 100 for oak, 130 for pine, the thickness t being supposed relatively small. d is then the mean diameter.

For pillars of ordinary lengths—

$$\frac{W}{A} = \frac{f}{1 + \frac{1}{a}\left(\frac{N\rho}{t} + \frac{l^2}{\rho^2}\right)}$$

* Based on data recorded by Professor W. E. Lilley in Amer. Soc. C.E., 1912.

† Unless pillar is very securely fastened at ends, it should be regarded as round-ended.

Material	f	a
Nickel steel	54	2,800
Bessemer steel . . .	49	2,600
Mild steel	36	4,000
Mild steel, annealed .	27	5,000
Wrought iron . . .	24·5	4,500
Cast iron	49	1,300

For dry timber, Rankine gives $f = 3{\cdot}2$, $a = 3{,}000$.
A factor of safety of 5 or 6 is generally allowed.

Eccentrically loaded or initially bent pillars.

Let e = eccentricity of loading in inches ; = $\frac{4}{5}$ of distance from centre of section at middle from line of action of load (if initially bent).
y = distance of outer fibre from neutral axis in inches.

$$\text{Then } \frac{W}{A} = \frac{f}{\left(1 + \frac{N\rho}{at}\right)\left(1 + \frac{ey}{\rho^2}\right) + \frac{l^2}{a\rho^2}}$$

For solid pillars put $\frac{N\rho}{at} = 0$.

Example.—A hollow circular pillar, 12″ external and 10″ internal diameter, 30 feet long is loaded centrally. If the pillar is initially bent 3·75″ out of the straight, find the collapsing load. Assume pillar of steel, having fixed ends.

$\rho^2 = \frac{1}{16}(d_1^2 + d_2^2) = \frac{1}{16}(144 + 100) = 15{\cdot}25$; $\rho = 3{\cdot}9$.

N = 500 ; $a = 5{,}000$; $t = 1$; $e = 4 \times 3{\cdot}75/5 = 3$; $y = 6$; $l = 30 \times 12/2 = 180$.

A = ·785 (144 − 100) = 34·5. $f = 27$.

$$\text{Hence } \frac{W}{34{\cdot}5} = \frac{27}{\left(1 + \frac{500 \times 3{\cdot}9}{5{,}000 \times 1}\right)\left(1 + \frac{3 \times 6}{15{\cdot}25}\right) + \frac{180 \times 180}{5{,}000 \times 15{\cdot}25}}$$

or W = 450 tons = collapsing load.

Working load = W ÷ factor of safety, say 5, = 90 tons.

Note.—Values of ρ for various standard sections are given on p. 75 ; and values of $A\rho^2$ for other sections on pp. 313–317.

Crippling Loads of Solid or Thick Mild Steel Pillars.

(In accordance with the formula above, using the constants for mild steel annealed, l = length in inches if ends are rounded, = half length if ends are fixed ; ρ = least radius of gyration in inches. Load is in tons per square inch.)

l/ρ	0	10	20	30	40	50	60	70
Crippling load	27·0	26·5	25·0	22·9	20·5	18·0	15·7	13·4
l/ρ	80	90	100	110	120	130	140	150
Crippling load	11·8	10·3	9·0	7·9	6·96	6·17	5·49	4·91

Maximum Compressive Stress in Thin Steel Rectangular Plates.*

Let thickness be t ins., length l ins., and maximum compressive stress in the direction of the length f_1 tons per square inch, then, if the breadth of the plate is very large compared with its length, $f_1 = 12{,}000\, t^2/l^2$.

If the breadth of the plate be b ins., multiply f_1 by the factor k in the table below :—

b/l	∞	3	2	1·5	1·25	1·0	·75	·5	·33	·25
k	1	1·24	1·56	2·08	2·69	4	7·7	16	36	64

It is above assumed that the edges of the plate are simply supported. If they are rigidly fixed make l and b one-half the length and breadth respectively ; if partly fixed, as at beams and stiffeners, reduce l and b by an intermediate ratio (say ·75), using judgment.

If the compressive stress f_1 also acts across the plate so as to produce uniform compression f_1 in all directions,

$$f_1 = 12{,}000\, t^2\left(\frac{1}{l^2} + \frac{1}{b^2}\right).$$

If the compressive stress across the plate be f_2 (different from f_1), the plate collapses when $12{,}000\, t^2\left(\frac{m^2}{l^2} + \frac{n^2}{b^2}\right)^2 = f_1\frac{m^2}{l^2} + f_2\frac{n^2}{b^2}$;

where m and n are integers chosen so that f_1 and f_2 are as small as possible. If one of the stresses be tensile, change the sign of f_1 or f_2. For a material other than steel replace 12,000 by $8E/9$.

Strength of Thin Hollow Cylinders and Spherical Shells under Internal Pressure.

P = internal pressure in tons per square inch.
T = tensile stress in material in tons per square inch.
t = thickness of material in inches.
r = radius in inches.

For Thin Hollow Cylinders.

$$P = \frac{Tt}{r} \qquad t = \frac{Pr}{T} \qquad T = \frac{Pr}{t}$$

The longitudinal tension is one-half the circumferential tension T. For Board of Trade rules *re* cylindrical boilers, see p. 452.

* These results are based on a paper by Professor G. H. Bryan, London Math. Soc. Proc., 1891.

For Thin Spherical Shells.

$$\text{P} = \frac{2\text{T}t}{r} \qquad t = \frac{\text{P}r}{2\text{T}} \qquad \text{T} = \frac{\text{P}r}{2t}$$

Strength of Thick Hollow Cylinders and Spherical Shells under Pressure.

Let R_1, R_2 = internal and external radii in inches.
p_1, p_2 = internal and external pressures in tons per square inch.
T = tensile circumferential stress at any point in tons per square inch.
p = compressive radial stress at any point in tons per square inch.

For thick Cylinders.

$$\text{At radius } x,\ \text{T} = \frac{1}{\text{R}_2^2 - \text{R}_1^2}\left\{\frac{\text{R}_1^2\text{R}_2^2(p_1 - p_2)}{x^2} + p_1\text{R}_1^2 - p_2\text{R}_2^2\right\}$$

$$p = \frac{1}{\text{R}_2^2 - \text{R}_1^2}\left\{\frac{\text{R}_1^2\text{R}_2^2(p_1 - p_2)}{x^2} - p_1\text{R}_1^2 + p_2\text{R}_2^2\right\}$$

When $p_2 = o$, greatest value of T is at internal circumference, and $= p_1\dfrac{\text{R}_2^2 + \text{R}_1^2}{\text{R}_2^2 - \text{R}_1^2}$

For thick Spheres.

$$\text{At radius } x,\ \text{T} = \frac{1}{\text{R}_2^3 - \text{R}_1^3}\left\{\frac{\frac{1}{2}\text{R}_1^3\text{R}_2^3(p_1 - p_2)}{x^3} + p_1\text{R}_1^3 - p_2\text{R}_2^3\right\}$$

$$p = \frac{1}{\text{R}_2^3 - \text{R}_1^3}\left\{\frac{\text{R}_1^3\text{R}_2^3(p_1 - p_2)}{x^3} - p_1\text{R}_1^3 + p_2\text{R}_2^3\right\}$$

When $p_2 = o$, greatest value of T is at internal circumference, and $= p_1\dfrac{\frac{1}{2}\text{R}_2^3 + \text{R}_1^3}{\text{R}_2^3 - \text{R}_1^3}$

Collapsing Pressure of Thin Hollow Cylinders.

Let l = length in inches.
r = mean radius in inches.
t = thickness in inches.
P = collapsing pressure in tons per square inch.

For short wrought-iron or steel tubes—at least $\frac{3}{8}''$ thick,

$$\text{P} = \frac{2{,}150t^2}{lr}$$

For long tubes $\text{P} = \dfrac{3{,}700\,t^3}{r^3}$. If ribbed, calculate the moment of inertia of the perimeter, assumed unrolled flat, and divide it by that of the same plate unribbed. Multiply P by this ratio.

Shear and Resultant Stresses

1. Each shear stress is accompanied by another equal shear stress in a perpendicular plane.

2. These two shear stresses are also equivalent to equal tensile and compressive stresses across planes inclined at 45°., e.g. in fig. 195, on p. 310, a shear stress along AB is necessarily accompanied by one along AC; these produce an equal tension across AC and an equal compression across BD.

3. Two tensile or compressive stresses p_1 and p_2 (put one of them negative if they are of opposite signs) together with stresses q in perpendicular planes are equivalent to a maximum direct stress of $\frac{1}{2}(p_1+p_2) + \sqrt{\frac{1}{4}(p_1-p_2)^2+q^2}$ and a maximum shear stress of $\sqrt{\frac{1}{4}(p_1-p_2)^2+q^2}$, these being in planes inclined at 45° to one another.

4. A bending moment M combined with a twisting moment T produce a maximum direct stress such as would be caused by an equivalent bending moment of $\frac{1}{2}(M + \sqrt{(M^2+T^2)})$; the maximum shear stress is equal to that caused by an equivalent twisting moment $\sqrt{(M^2+T^2)}$.

5. The shear stress permissible varies from one-half to the full tensile stress permissible; about 80 per cent is frequently taken. (See riveted joints, shafts, plate web girders.)

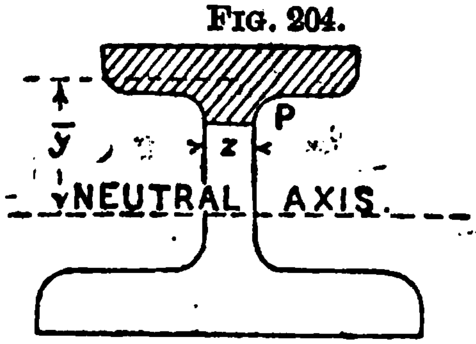
Shear Stress in Beams.

To find the shear stress at a point P in the section (fig. 204), let

F = shearing force at section in tons.
I = moment of inertia of section about neutral axis in (inches)^4.
A = area (shaded) of portion of section lying beyond P in square inches.
$\bar{y}$ = distance of centre of gravity of area A from neutral axis in inches.
z = thickness of web or breadth of section at P in inches.
q = shear stress in tons per square inch.

$$q = FA\bar{y}/Iz.$$

Fig. 204.



Note.—The shear stress is very small in the flanges or horizontal portions of a beam. In an I beam of ordinary proportions it is practically constant over the web, and equal to F ÷ web area.

Plate Web Girders.

F = shearing force in tons.
D = depth of web in inches.
t = thickness of web in inches.
s = spacing of stiffeners in inches.
s' = spacing of rivets connecting web to flanges or in web seams in inches.
V = shearing or bearing value (whichever is less) of one rivet in tons, taken in single or double shear as the case may be (pp. 286-8).
n = number of rows of rivets.

$t = \text{F}/2{\cdot}5\,\text{D}$ (minimum).

$$s^2 = 1500t^2\left(\frac{5\,\text{D}t}{\text{F}} - 1\right).$$

$s' = n\text{VD}/\text{F}$.

Note.—(1) It is assumed above that the shearing stress allowable is one-half the tensile strength, and that the latter is 5 tons per square inch. For any other tensile strength f, change F to $5\text{F}/f$. (2) It is frequently advisable to make t thicker than would be given by the first formula in order to avoid too close spacings of stiffeners or rivets. (3) The *size* of the stiffeners can only be determined by experience, e.g. make total weight of stiffeners the same proportion of weight of web as in a similar successful design.

Example.—Design a solid plate transverse frame of a large ship; spacing 4 feet, depth 3 ft. 6 in., weight of ship 70 tons per foot run, $f = 8$ tons per square inch.

A rough estimate of F is found by assuming half the weight of the ship to be taken on centre when in dock, the remainder being taken on the side docking blocks. Then F near keel is $\frac{1}{4}$ the weight over a length of one frame space, or 70 tons.

Change F to $5\text{F}/f$ or to 45 approximately.

Then $t = 45/2{\cdot}5 \times 42 = {\cdot}43$ inch minimum.

On trial this would be found rather small; take $t = \frac{1}{2}''$.

$$s^2 = \frac{1500}{4}\left(\frac{5 \times 42 \times {\cdot}5}{45} - 1\right) \text{ or } s = 22{\cdot}4''; \text{ so that the}$$

stiffeners should be spaced about 2 feet apart.

To obtain V, assume rivets $\frac{7}{8}''$ diameter. Shear value from table is 2·76 tons. Take $n = 1$; then $s' = 2{\cdot}76 \times 42/45 =$ about $2\frac{1}{2}$.

Shafts.

H = horse-power transmitted.
T = torque or twisting moment in inch-tons.
d_1, d_2 = external and internal diameters of shaft in inches.
q = maximum shear stress in tons per square inch.
C = coefficient of rigidity in tons per square inch; = 5,500 for steel.
θ = angle of twist of shaft over length l feet in degrees.
N = number of revolutions per minute.

$$\frac{T}{\frac{\pi}{32}(d_1^4 - d_2^4)} = \frac{q}{\frac{1}{2}d_1} = \frac{\pi C \theta}{2160 l}$$

$T = \cdot 196 q\ (d_1^4 - d_2^4)/d_1 = q \times$ torsional modulus of section.
θ (steel shafts) $= 1\cdot 27\ Tl/(d_1^4 - d_2^4) = \cdot 25\ ql/d_1$.
$TN = 28\cdot 2\ H$.
$H = qN\ (d_1^4 - d_2^4)/147 d_1 = \cdot 426\ qN \times$ torsional modulus of section.

The torsional modulus of section and polar moment of inertion for shafts of various signs are tabulated on pp. 318, 319; see note at foot of tables.

Working Values of Shear Stress q (tons per square inch).

Wrought iron	about $3\frac{1}{2}$
Forged steel (from scrap)	4 to $4\frac{1}{2}$
Forged steel (ingot)	5
Cast iron	3
Gunmetal	2
Copper	$1\frac{3}{4}$

Note.—The stress allowed depends on the fluctuation of load. Where load varies greatly, as in factory shafting, take about $\frac{2}{3}$ the above values. In ordinary engines divide q by the ratio in which the maximum torque exceeds the mean, i.e. by 1·6 with single cylinders, by 1·1 with two, and by 1·05 with three or more cylinders.

When the shaft is subjected also to a bending moment M, substitute for T the equivalent twisting moment $M + \sqrt{M^2 + T^2}$.* Frequently the size of the shaft is determined from considerations of stiffness; the twist in long shafts should not exceed 1° in 20 diameters' length, which makes q about $2\frac{1}{2}$.

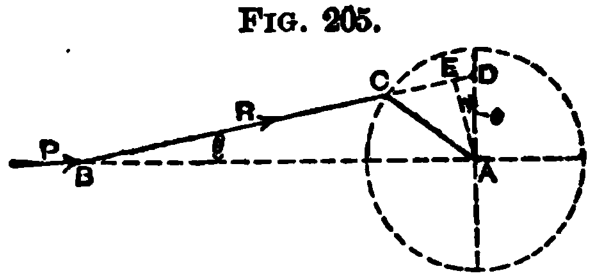
For Board of Trade Rules, see pp. 464 and 465.

Square Shafts.

See note at foot of table on p. 336.

TWISTING MOMENT OF A CRANK.

FIG. 205.



Let AB = centre line through cylinder and shaft in inches.
AC = line through centre of crank.
AD = line at right angles to AB.

* This gives the maximum *direct* stress, which is usually taken as a criterion of a shaft's strength. To get the maximum shear stress, take the moment $\sqrt{M^2 + T^2}$.

BC = connecting rod.
CD = line BC produced.
AE = line perpendicular to BD.
P = load on the piston.
R = thrust on connecting rod.
θ = angle ABC = angle EAD.

Twisting moment = R $\times$ AE = R $\times$ AD cos θ = P $\times$ AD.

Couplings.

Flanged Couplings.

End of shaft enlarged to 1·12 diameter to take keyway.
If d = shaft diameter in inches,
Number (N) of bolts $= \frac{1}{2}d + 3$ for shafts over $1\frac{1}{2}$" diameter.

Diameter of body of coupling $= 2d + 1''$.

Diameter (δ) of bolt $= \cdot 6d / \sqrt{N}$.

Diameter over flange $= 2d + 1'' + 6\frac{1}{2}\,\delta$.

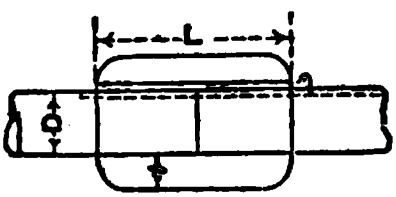
Thickness of each flange $= \cdot 5d + \cdot 25$.

Total length of coupling $= 2\frac{1}{2}d + 1\cdot 25$.

Diameter of recess for bolts $= 2\cdot 5\delta$.

Box Coupling.

FIG. 206.



$L = 3D + 1\frac{1}{2}''$

$t = \cdot 45D + \frac{1}{4}''$.

Bearings.

Distance between bearings in line shaft loaded with pulleys.

Diameter of shaft in inches	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
Distance in feet . . .	7	8	9	10	11	12	13

Distance between bearings for high speed unloaded shaft.

Distance in feet $= 175 \sqrt[4]{\frac{d_1^2 + d_2^2}{N^2}}$. (Symbols as on p. 333.)

For a ship's shaft with thrust, change 175 to about 160.

Working Pressure on Bearings.

	Pressure in lb. per square inch of projected area ($l \times d$).	
Main crank-shaft bearings .	200	(slow).
" " " .	300	(fast passenger).
" " " .	300	(warships).
" " " .	500	(T.B. destroyers).
Line shafting on gun-metal	200	
" " cast iron .	50	
Pivots on gun-metal . .	200	to 500.
" lignum vitæ . .	1,200	

Also pressure in lb. per square inch multiplied by rubbing speed in feet per minute should not exceed 50,000.

Section of Material.		Circle. diam. = d.	Square. side = d.	Rectangle. sides = b, d, $b > d$ (approximate).	Ellipse. diam. = b, d, $b > d$.
$\delta = \dfrac{\text{W}n\,\text{D}^3}{\text{C}d^4}$	$\times$	$\dfrac{1}{280}$	$\dfrac{1}{400}$	$\dfrac{(b^2+d^2)d}{800b^3}$	$\dfrac{(b^2+d^2)d}{560b^3}$
$f = \dfrac{\text{WD}}{d^3}$	$\times$	$\dfrac{1}{880}$	$\dfrac{1}{930}$	$\dfrac{bd+0\cdot6d^2}{1500b^2}$	$\dfrac{d}{880b}$
$\delta = \dfrac{fn\,\text{D}^2}{\text{C}d}$	$\times$	$3\cdot14$	$2\cdot32$	$\dfrac{1\cdot88\,(b^2+d^2)}{b^2+0\cdot6bd}$	$1\cdot57\left(1+\dfrac{d^2}{b^2}\right)$
When $\text{C} = 5{,}500$, $f = 25$.					
$\delta = \text{W}n\,\text{D}^3/1{,}000{,}000\,d^4$	$\times$	$\dfrac{1}{1\cdot54}$	$\dfrac{1}{2\cdot2}$	$\dfrac{(b^2+d^2)d}{4\cdot4b^3}$	$\dfrac{(b^2+d^2)d}{3\cdot08b^3}$
$\text{W} = d^3/\text{D}$	$\times$	22,000	23,300	$\dfrac{37{,}500b^2}{bd+0\cdot6d^2}$	$22{,}000\,b/d$
$\delta = n\text{D}^2/d$	$\times$	$\dfrac{1}{70}$	$\dfrac{1}{94\cdot5}$	$\dfrac{b^2+d^2}{118b\,(b+0\cdot6d)}$	$\dfrac{1}{140}\left(1+\dfrac{d^2}{b^2}\right)$

Note.—A square section is 6 per cent stronger and 48 per cent stiffer than the circular section inscribed.

HELICAL SPRINGS (see table opposite).

D = mean diameter of coil in inches (from $3d$ to $8d$ in general).

b, d = size of section in inches (b greater than d, see table).

n = number of complete turns of coil.

W = load in lb.

δ = deflection in inches under load W.

f = shear stress due to W in tons per square inch = about 25 for ordinary working loads in tempered springs (9·1 in circular and 11·8 in square safety valve springs under Board of Trade Rules).

C = coefficient of rigidity in tons per square inch = 5,500 for ordinary steel, up to 8,000 in special steels.

FREQUENCY OF VIBRATION.

N = number of complete (to and fro) vibrations per minute.

The material is assumed to be steel, having Young's modulus = 13,500 tons per square inch, and coefficient of rigidity = 5,500 tons per square inch. For any other material the frequency is proportional to the square root of the elastic coefficient.

Conditions.	N.
1. Mass hung from spring which deflects δ in. .	$188/\sqrt{\delta}$
2. Mass W lb. hung from spring with n coils diam. D in., diam. of iron d in. (W includes $\frac{1}{3}$ mass of spring).	$\dfrac{223{,}000d^2}{\sqrt{\mathrm{W}n\mathrm{D}^3}}$
3. Mass as above, radius of gyration K in., torsional vibration.	$\dfrac{129{,}000d^2}{\mathrm{K}\sqrt{\mathrm{W}n\mathrm{D}}}$
4. Mass as above, suspended by wire diam. d in., length l in.	$\dfrac{206{,}000\,d^2}{\mathrm{K}\sqrt{\mathrm{W}l}}$
5. Taut wire rope, circumference C in., length l ft., tension t lb.	$\dfrac{440}{\mathrm{C}l}\sqrt{t}$
6. Do., but weight W lb. given in lieu of circumference.	$170\sqrt{\dfrac{t}{\mathrm{W}l}}$
7. Weight W lb. on the end of rectangular cantilever l ft. long, moment of inertia of section I in inch units, about axis perpendicular to plane of vibration.	$\sqrt{\dfrac{\mathrm{I}}{\mathrm{W}l^3}}$ × 43,000
8. As above, but weight W at middle of beam l ft. long, ends free.	× 172,000
9. As above, but ends of beam fixed in direction	× 86,000
10. As 7, but weight uniformly distributed . . .	× 88,000
11. As 8, ,, ,, . . .	× 250,000
12. As 9, ,, ,, . . .	× 550,000
13. Uniform bar unsupported	× 550,000

Rings.

D = mean diameter of ring in inches.
d = diameter of iron in inches.

Proof load in tons $= 19d^3/\text{D}$.

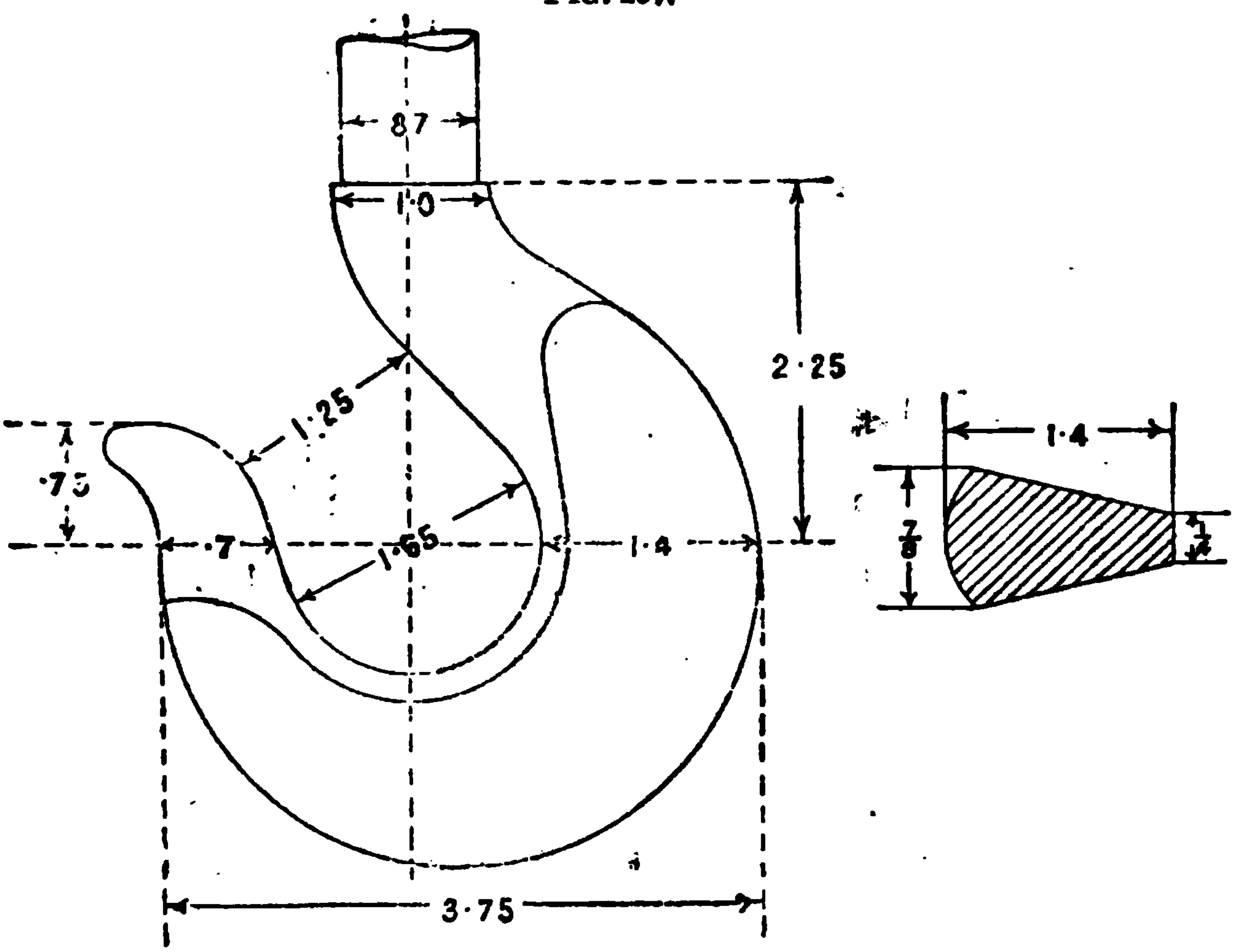
Working load = one-half proof load.

The Admiralty proof test for standard rings and ring bolts, where $\text{D} = 5d$, is $4d^2$.

Hooks.

The following proportions and working loads of crane hooks are given by Mr. Towne (fig. 207). If the top be formed into an eye, make external diameter of eye 1·8, internal diameter ·7.

FIG. 207.



Diameter in inches.	Safe load in lb.	Safe load in tons.	Diameter in inches.	Safe load in lb.	Safe load in tons.	Diameter in inches.	Safe load in lb.	Safe load in tons.
$\frac{5}{8}$	590	·26	$1\frac{1}{4}$	2,420	1·08	$1\frac{7}{8}$	5,370	2·4
$\frac{3}{4}$	830	·37	$1\frac{3}{8}$	2,820	1·26	2	6,080	2·7
$\frac{7}{8}$	1,200	·63	$1\frac{1}{2}$	3,450	1·54	$2\frac{1}{4}$	7,700	3·4
1	1,480	·66	$1\frac{5}{8}$	3,910	1·75	$2\frac{1}{2}$	9,460	4·2
$1\frac{1}{8}$	1,870	·83	$1\frac{3}{4}$	4,720	2·10	$2\frac{3}{4}$	11,400	5·1

For heavier loads take square of diameter to vary as the load.

British Standard Keys and Keyways.*

(See table on following page.)

The keys to be cut from standard key-bars whose width and thickness are ·002 inch greater than nominal size of key. Keys whose length is not more than $1\frac{1}{2}$ diameters of shaft to have a taper in thickness of 1 in 100. Nominal thickness is that at large end. The depth of keyway at centre line to be $\frac{1}{2}$ thickness of key.

Screwed Bolts.

The strength of a screwed bolt under shear, or under tension if not screwed too tightly, is about three-quarters that of a bar or rivet whose area is that of the bolt to the bottom of the thread.

Under tension an unknown factor is usually introduced by the stress caused by screwing up. In the following table allowance is made for this.

Working stress (f) in lb. per square inch of screwed bolts.
(H. J. Spooner, Esq.)

	f for steel.	f for iron.
Largest sizes of bolts and studs	6,000	4,800
Under $\frac{7}{8}''$ diameter . . .	4,500 to 3,000	3,600 to 2,400
	(least stress in smallest sizes)	
Ordinary marine practice . .	5,000	4,000
Cylinder under 10″ diameter .	2,500	2,000

For rougher joints with packing which must be compressed to make the joints tight, halve the above values.

For areas of screwed bolts to the bottom of thread, see p. 535.

Pressure of Water on Dock Gates.

D = depth of water in feet.
L = length of one gate in feet.
T = mutual pressure between gates at middle in lb.
N = normal water pressure on one gate in lb.
d = distance from point where gates meet to a right line joining their hinges.

$$T = \frac{16D^2L^2}{d} \qquad N = 32LD^2$$

* Reproduced by permission of the Engineering Standards Committee from their Report No. 46, British Standard Specification for Keys and Keyways, published by Messrs. Crosby Lockwood & Son. Price 2s. 6d.

(See p. 339.)

TABLE OF DIMENSIONS IN INCHES.

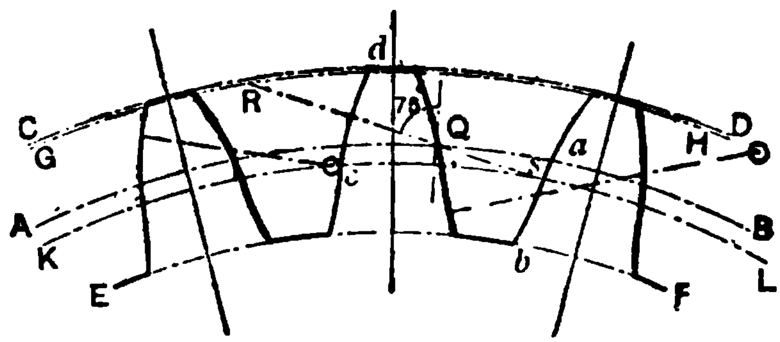
Designation B. S. K.	Shaft diam.		Key.		Key-bar.					Keyway.		
	Over.	To.	Nominal width.	Nominal thickness at large end.	Minimum width.	Minimum thickness.	Margin of manufacture on width and thickness.	Maximum width.	Maximum thickness.	Minimum width.	Tolerance.	Maximum width.
1	1·25	1·50	0·375	0·2500	0·377	0·2520	+ ·002	0·379	0·2540	0·3740	— ·0010	0·375
2	1·50	2·00	0·500	0·3750	0·502	0·3770	”	0·504	0·3790	0·4985	— ·0015	0·500
3	2·00	2·50	0·625	0·4375	0·627	0·4395	”	0·629	0·4415	0·6235	— ·0015	0·625
4	2·50	3·00	0·750	0·5000	0·752	0·5020	”	0·754	0·5040	0·7480	— ·0020	0·750
5	3·00	3·50	0·875	0·6250	0·877	0·6270	+ ·003	0·880	0·6300	0·8730	— ·0020	0·875
6	3·50	4·00	1·000	0·6875	1·002	0·6895	”	1·005	0·6925	0·9980	— ·0020	1·000
7	4·00	5·00	1·250	0·8125	1·252	0·8145	”	1·255	0·8175	1·2480	— ·0020	1·250
8	5·00	6·00	1·500	1·0000	1·502	1·0020	+ ·004	1·506	1·0060	1·4975	— ·0025	1·500
9	6·00	7·00	1·750	1·1875	1·752	1·1895	”	1·756	1·1935	1·7475	— ·0025	1·750
10	7·00	8·00	2·000	1·3750	2·002	1·3770	”	2·006	1·3810	1·9970	— ·0030	2·000
11	8·00	10·00	2·500	1·6250	2·502	1·6270	+ ·005	2·507	1·6320	2·4970	— ·0030	2·500
12	10·00	12·00	3·000	2·0000	3·002	2·0020	”	3·007	2·0070	2·9960	— ·0040	3·000

TOOTHED-WHEEL GEARING.

Easy Method of Setting Out the Teeth. (Fig. 208).

Let AB be the pitch circle. From the same centre draw circles CD, EF, so that their distances from the pitch circle are

FIG. 208.

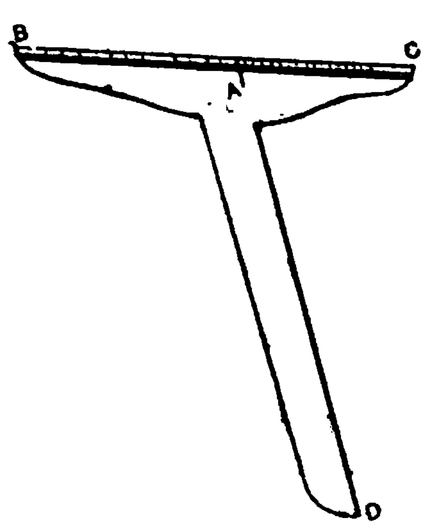


respectively ·35 P and ·45 P (P being the pitch). The points of the teeth will end on CD, and the roots on EF.

Round the pitch circle AB, set off the pitch and the edges of the teeth, making the thickness of each tooth ·45 P.

Through the edge Q of one of the teeth draw RQS inclined at an angle of 75° to the radius through Q. Make RQ equal to ·95 P and QS ·55 P; and through R and S draw circles GH, EF. From R as centre strike in the curve *ab* for the lower half of the tooth, and keeping this radius constant and the centres always

FIG. 209.



on the circle GH, draw the lower half of each tooth in turn. Then from centre S strike in the curve *cd* for the upper half, and keeping the centres on KL, and the same radius, draw in

the upper half of each tooth. The complete shape of each tooth is now drawn in.

In order to draw the line RQS, the instrument shown in fig. 209 is often used.

The parts BC and AD are inclined at 75°, and from A two scales are set off along AB and AC, so that QR and QS may be at once measured when the pitch is given in inches.

This method gives a tooth approximating to involute form; it is sufficiently accurate for gears working sluice valves, W.T. doors, etc., where evenness of running is of minor importance.

Usual Proportions of Teeth.

	Common pattern Moulded Wheels.	Machine Moulded Wheels.	Worm Wheels.
Pitch line to tip . . .	·33 p	·3 p	·3 p
Pitch line to root . . .	·42 p	·4 p	·37 p
Total depth	·75 p	·7 p	·67 p
Thickness at pitch line .	·45 p	·48 p	·48 p
Width of teeth—large .	2 p	2 p	1·5 p
,, ,, small .	3 p	3 p	2 p

Length of worm, 4 p; p = pitch.

Limiting Speeds of Toothed Gears.

(Mr. A. Towler.)

	ft. per min.
Ordinary cast-iron wheels	1,800
Helical ,, ,, ...	2,400
Mortise ,, ,, ...	2,400
Ordinary cast-steel wheels . . .	2,600
Helical ,, ,, ...	3,000
Special cast-iron machine-cut wheels .	3,000

Strength of Cast-iron Teeth.

P = pressure in pounds transmitted (assumed concentrated on one tooth).

f = stress allowable in lb. per square inch.

b = breadth of tooth in inches.

p = pitch in inches.

Then $f = 10{,}000/\sqrt{\text{speed at pitch circle in feet per second}}$; this is given approximately by the following table:—

Speed—ft. per min.	100 or less	200	300	600	900	1200	1800	2400	3000
f	8000	5500	4500	3200	2500	2200	1800	1600	1500

$$P = \cdot 05 f p b.$$

Relation of Horse-power Transmitted and Velocity at the Pitch Circle to Pressure of Teeth.

Number of Horses' Power Transmitted	Velocity in Feet per Minute.									
	60	180	300	420	540	660	780	900	1200	1500
H.P.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
1	550	183	110	79	61	50	42	37	28	22
2	1,100	367	220	157	122	100	85	73	55	44
3	1,650	550	330	236	183	150	127	110	83	66
4	2,200	733	440	314	224	200	169	146	110	88
5	2,750	917	550	393	306	250	212	183	138	110
10	5,500	1,833	1,100	786	611	500	423	367	275	220
15	8,250	2,750	1,650	1,179	917	750	635	550	413	330
20	11,000	3,667	2,200	1,571	1,222	1,000	846	733	550	440
25	13,750	4,583	2,750	1,964	1,527	1,250	1,058	917	688	550
30	16,500	5,500	3,300	2,357	1,833	1,500	1,269	1,100	825	660
40	22,000	7,333	4,400	3,143	2,444	2,000	1,692	1,467	1,100	880
50	27,500	9,167	5,500	3,928	3,055	2,500	2,115	1,833	1,375	1,100
60	33,000	11,000	6,600	4,714	3,667	3,000	2,538	2,200	1,650	1,320
70	38,500	12,833	7,700	5,500	4,278	3,500	2,962	2,567	1,925	1,540
80	44,000	14,667	8,800	6,285	4,889	4,000	3,385	2,933	2,200	1,760
90	49,500	16,500	9,900	7,071	5,500	4,500	3,808	3,308	2,475	1,980
100	55,000	18,333	11,000	7,857	6,111	5,000	4,231	3,667	2,750	2,200
110	60,500	20,167	12,100	8,643	6,722	5,500	4,654	4,033	3,025	2,420
120	66,000	22,000	13,200	9,423	7,333	6,000	5,077	4,400	3,300	2,640
130	71,500	23,833	14,300	10,214	7,944	6,500	5,500	4,767	3,575	2,860
140	—	25,667	15,400	11,000	8,556	7,000	5,923	5,133	3,850	3,080
150	—	27,500	16,500	11,786	9,167	7,500	6,346	5,500	4,125	3,300
160	—	29,333	17,600	12,571	9,778	8,000	6,769	5,867	4,400	3,520
170	—	31,167	18,700	13,357	10,389	8,500	7,192	6,233	4,675	3,740
180	—	—	19,800	14,143	11,000	9,000	7,615	6,600	4,950	3,960
190	—	—	20,900	14,929	11,611	9,500	8,038	6,967	5,225	4,180
200	—	—	22,000	15,714	12,222	10,000	8,462	7,333	5,500	4,400
300	—	—	33,000	23,571	18,333	15,000	12,692	7,700	8,250	6,600
400	—	—	44,000	31,428	24,444	20,000	16,923	8,067	11,000	8,800
500	—	—	55,000	39,285	30,555	25,000	21,154	8,433	13,750	11,000

Note.—1. For roughly-cut wheels where the whole pressure may come on one corner of the tooth, make b in the formula $1\frac{1}{2}\,p$ whatever its actual value.

2. Mr. W. Lewis has shown that the coefficient in the above formula is ·067 for well-shaped teeth; and that it increases according to the number of teeth.

Number of teeth . . .	20	30	50	rack.
Coefficient—radial flanks . .	·06	·065	·069	·075
„ well-shaped teeth.	·09	·102	·112	·124

3. For teeth liable to sudden shocks f should be halved.

4. The pressure P is related to the horse-power H, the pitch diameter d inches and the revolutions per minute N by the formula $\text{PN}d = 126{,}000$. The relation between power, pressure, and velocity is expressed in the table on p. 343.

5. For teeth of materials other than cast iron, multiply f by the multipliers below; or alternatively multiply the pitch deduced from the formulæ by the relative pitches below, keeping proportions the same.

Material.	Wood.	Gun-metal.	Cast Steel.	Wrought Iron.	Phosphor Bronze.	Nickel Steel.	Vanadium Steel.
Multiplier for f—		1·5	2·1	2·3	2·3	3·7	4 to 5
Relative pitch	1	·82	·69	·65	·65	·52	·5 to ·45

Wood teeth, although weaker than iron, are differently proportioned so that their relative pitch is about the same.

6. The least number of teeth (Unwin) $= 791\text{H}/p^3\text{N}$ for iron and $951\text{H}/p^3\text{N}$ for mortise.

7. To secure quiet running of wheel gears the diameter should be kept low so as to reduce the peripheral velocity; to secure adequate strength the teeth should be as short and wide as possible.

Dimensions of Propeller Struts ('A' Brackets).

(A. W. Johns, Esq., M.I.N.A.)

The size of the struts may be determined from the stresses caused by the loss of one propeller blade. The strength should be the same as that of the end of the shaft under the same conditions. This gives the following formula for a cast-steel bracket :—

$$\text{R}^2 r = \cdot 62\frac{m}{a}\cdot\frac{\text{D}^4 - d^4}{\text{D}}\cos\frac{\theta}{2}\text{, where}$$

R, r = the greatest and least dimensions of the arms (R is commonly about $3{\cdot}5\,r$).

D, d = the external and internal shaft diameters.

m = longitudinal overhang from centre of propeller to centre of bracket.

a = longitudinal clear overhang from centre of propeller to after end of bearing on bracket.

θ = angle between arms of bracket.

All in inch units.

Length of bearing is commonly about $5\frac{1}{2}$ D; it is determined from the bearing pressure, which should not exceed about 20 lb. per square inch projected area. Thickness round bearing (*ex* bush and gland) about $\frac{1}{2}r$.

LONGITUDINAL STRESSES IN SHIPS.

The vessel is assumed to float in a wave of its own length (*b.p.*) whose height is $\frac{1}{20}$ the length.* The maximum B.M. is calculated when the middle of length lies over (*a*) the crest of the wave, (*b*) the trough; these moments being termed hogging and sagging respectively. Regarding the ship as a beam, the moment of inertia is calculated amidships, or at any weakened section near amidships; the stresses in keel and upper works are then calculated by the ordinary beam formulæ. These stresses are usually limited to certain amounts appropriate to the conventional conditions assumed.

Practical Construction of Bending Moment Curves.

1. At sections spaced about one-twentieth † of the length draw curves of areas or 'bonjean' curves. These curves give the immersed area of each section at any draught. They are conveniently constructed with the help of an integraph; or otherwise the information on the displacement sheet should be utilized.

2. Set off the wave on a contracted longitudinal scale; the vertical scale should be the same as that adopted in the above curves. The wave is assumed trochoidal; it may be constructed as on p. 34, or by means of the following table which gives the proportions of a standard trochoidal wave.

x	0	1	2	3	4	5	6	7	8	9	10
h	0	·034	·128	·266	·421	·577	·720	·839	·927	·982	1

x = distance from crest divided by $\frac{1}{20}$ length.
h = depth of wave surface below crest divided by height of wave (or by $\frac{1}{20}$ length).

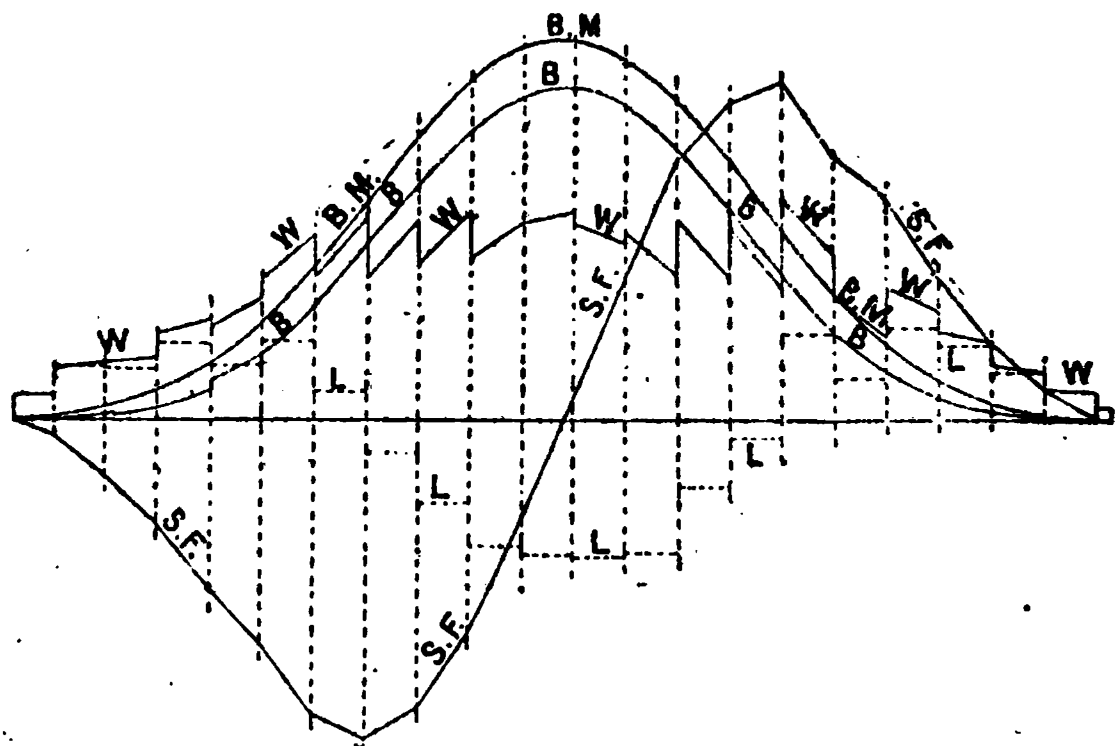
3. Determine the weight and centre of gravity (longitudinal) of the ship. It is usual to assume that condition which provides the greatest B.M.; e.g., for hogging take out all midship weights such as coal, reserve feed-water, etc., and for sagging take bunkers and midship tanks full.

* A more logical assumption is to limit this ratio to ships less than 470 feet in length. In longer ships the height should vary as the square root of the length, thus 24·2′ for 500′, 25·4′ for 550′, 26·5′ for 600′, 28·6′ for 700′, 30·6′ for 800′, and so on. This leads to calculated stresses of reasonable magnitude in even the largest ships. The proportions given above for a standard trochoidal wave then no longer hold.

† One-tenth spacing is sometimes sufficient. The number of divisions depends on the regularity of the form of the ship; in most cases the 'one-twentieth' need only be used at the ends.

4. Determine the position of the ship relative to the wave so that the displacement is equal to the known weight, and the longitudinal position of centre of buoyancy is below the known position of the C.G. This is done by trial and error; the midship section of the ship is maintained at the crest or hollow of the wave. Draw on the diagram of wave a line representing any fixed line in the ship—say, the load water-line. The position of this line is guessed in the first place; from it the draught at each section is measured, and thence the immersed area is obtained by the bonjean curves. From these areas the displacement and C.B. are calculated by Simpson's Rule. If these are not correct take a second line on the wave diagram, and so on until agreement is finally obtained.

FIG. 210.



5. On a base of length draw a curve of buoyancy in tons per foot of length, BBB in fig. 210. The ordinate of this curve is $\frac{1}{35}$ the immersed area of section—both sides.

6. Draw a curve of weight per foot run. This entails a rather laborious calculation which may be performed as follows: Divide the ship into compartments separated by the sections used in the buoyancy calculations. Take each item of weight from the weight calculation of the ship (p. 102) and distribute it, finding what amount lies within each compartment. Thus, the skin plating, if uniform, can be distributed by drawing a curve of girths, finding the area intercepted within each compartment, and multiplying this by the total weight divided by the total area. Framing is distributed by calculating weights of a few typical frames, and setting them off in a curve.

Concentrated items—engines, boilers, etc.—are easy to distribute, for they usually lie entirely in one or two compartments.

These component weights are placed in a table having a column for each compartment; by addition the total weight is found for each compartment. Set off in the middle of each compartment (fig. 210) the mean weight per foot run within, i.e. total weight ÷ length, and draw a line parallel to the corresponding portion of the buoyancy curve. This gives a stepped curve of weights WWW . . . The scale should be the same as for BBB . . .

7. Measure the intercept between the weight and buoyancy curves; set them off above the line for excess buoyancy and below the line for excess weight. This gives a series of rectangles forming a stepped curve of loads LLLL . . . .

8. Determine the area of each rectangle, counting negative below the line. Commencing from the left, set off the area of the first rectangle on the ordinate to the right; then the area of the first two rectangles on the ordinate to the right of the second; and so on, each ordinate representing to scale the area of the portion of the loads curve lying to the left. This gives the curve of shearing force S.F. (In fig. 210 it is shown reversed.) The curve should close at the extreme right-hand side.

9. In the same manner find the areas of portions of the S.F. curve, setting them off to scale on the right-hand ordinate. This gives the B.M. curve which should also close.

10. The maximum ordinate of the B.M. curve gives the bending moment required.

Alternative Method.

In order to avoid the laborious process described above, the weights of each half of the ship are often calculated separately, as shown for the battleship on p. 109. If this is done, proceed as indicated in paragraphs 1 to 5 above, and then as follows:—

6. Treat the buoyancy curve as directed above in par. 8 for the curve of loads, but commence from each end, and continue only as far as amidships. We thus get two curves whose ordinates represent the area of the buoyancy curve outside it—on the left for the left-hand portion, and on the right for the right-hand portion.

7. Treat these two curves in the same manner, again commencing from either end. As a result we have two curves which may be termed the curves of bending moment due to buoyancy.

8. Find the arithmetic mean of the two bending moments amidships as obtained from the curves just drawn. Call this M_b.

9. Find also the arithmetic mean of the moments of forward and after weights about amidships. Thus, in the battleship, p. 109, this is $\frac{1}{2}$ (1,694,800 + 1,052,250) or 1,373,500 foot tons. Call this M_w.

10. The difference between M_b and M_w is the required maximum B.M.

Approximate Values of B.M. in various classes.

W = normal displacement of ship in tons.

L = length of ship between perpendiculars.

Maximum B.M. = WL/K ; where K is about 25 for modern battleships, steam yachts and scouts, about 20 for destroyers and very fine vessels, 25 to 30 for liners, 30 to 35 for cargo ships and older battleships.

The hogging moments are usually greater than the sagging, except in very fine vessels. Warships using oil fuel are liable to have large hogging moments, unless the oil tanks are confined to the machinery space.

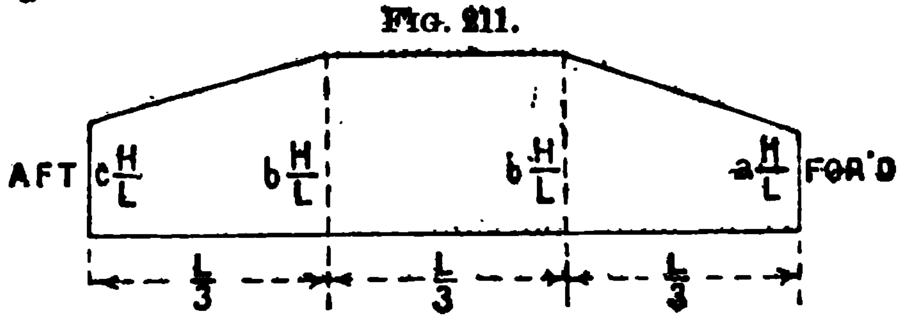
Short Method of constructing Weight Curve. (Sir J. A. Biles, LL.D.)

The labour involved in drawing the curve of weights is due principally to the hull items. In this method the curve is assumed to consist of three straight lines (fig. 211), the ordinates being $\frac{aH}{L}$, $\frac{bH}{L}$, and $\frac{cH}{L}$, where H = weight of hull in tons, L = length of ship in feet, and a, b, and c are coefficients depending on the type of ship. Note that $a + 4b + c = 6$ in all cases.

In an ordinary passenger or cargo vessel $a = {}$·566, $b = 1$·195, $c = {}$·653.

The weights of equipment, cargo, machinery, and fuel are readily distributed and added to the above distribution of hull weight.

Fig. 211.



Weight Curve for Warships.

In large warships a very close approximation to the distribution of hull weight is found by taking it $\frac{2}{3}$ as the buoyancy in still water and $\frac{1}{3}$ as a trapezoid proportioned so that its C.G. lies over that of the hull.

MOMENT OF INERTIA OF SECTION.

1. Roughly predict the position of the neutral axis, and draw in a trial axis near it.

2. Calculate for each portion of the structure which has longitudinal continuity the area A in square inches, the distance y feet from neutral axis assumed, and the depth d feet (for side plating and other vertical portions).

3. Arrange these in two tables (pp. 350 and 351), putting in one the portions above and in the other the portions below the N.A. Insert also the products Ay, Ay^2, and Ad^2.

4. Find the sums of A, Ay, Ay^2, and Ad^2; subtract one-twelfth of the last from the sum of Ay^2; call the difference I.

5. Taking the two portions find the sums of A and I, and the difference of Ay. Call these A^1, I^1, A^1y^1. The position of the real neutral axis from that assumed is equal to A^1y^1 divided by A^1; while the moment of inertia about the real neutral axis is $I^1 - (A^1y^1)^2/A$.

Thus, in the example—

	A	Ay	I
Above N.A.	2271	34,200	654,000
Below N.A.	1373	21,700	382,000
	3644	12,500	1,036,000 in.^{2} × ft.^{2}
		Excess above.	

Real neutral axis above assumed = 12,500/3,644 = 3·4 ft.

M.I. about real N.A. = 1,036,000 − (12,500)^2/3644 = 993,000 in.^{2} × ft.^{2}; or 1,986,000 for both sides of the ship.

6. The new distances y of N.A. from upper deck and keel are now found. They are 20·6′ and 23·5′ in the example.

7. The stress in tons per square inch is then My/I. That in the portion in tension is increased owing to the rivet holes; usually it is considered that $\frac{2}{11}$ of the area is thus lost, so that the stress must be increased by $\frac{11}{9}$. In the example—

Hogging.—M = 437,000 feet tons.

Tensile stress in upper deck $= \dfrac{437,000 \times 20\cdot6}{1,986,000} \times \dfrac{11}{9} = 5\cdot55$ tons per square inch.

Compressive stress in keel $= \dfrac{437,000 \times 23\cdot5}{1,986,000} = 5\cdot18$ tons per square inch.

Sagging.—M = 336,000 feet tons.

Compressive stress in upper deck $= \dfrac{336,000 \times 20\cdot6}{1,986,000} = 3\cdot48$ tons per square inch.

Tensile stress in keel $= \dfrac{336,000 \times 23\cdot5}{1,986,000} \times \dfrac{11}{9} = 4\cdot87$ tons per square inch.

Battleship 590′ × 90′ × 27′ × 25,000 tons.

PORTION ABOVE ASSUMED NEUTRAL AXIS.

Item.	Scantlings.	Area in sq. in. 'A'.	Distance from assumed N.A. 'y' ft.	Moment. Ay in^2 ft.	Moment of Inertia. Ay^2 in^2 ft.^{2}	Correction. Al^2.
Upper deck	39′ × 70 lb.	819	24·0	19656	471740	
Gunwale bar	6″ × 6″ × 37·5 ,,	11	23·2	255	5920	
Plating behind 6″ armour . .	8′ × 30 ,,	72	19·4	1397	27100	4610
Deck angle to main deck . .	6″ × 6″ × 28 ,,	8	15·6	125	1950	
Main deck	38′ 6″ × 14 ,,	162	15·8	2560	40450	
Angle underside main deck .	6″ × 6″ × 28 ,,	8	15·1	121	1830	
Plating behind 12″ armour .	12·2′ × 30 ,,	110	9·1	1001	9110	16400
Angle at heel of armour . .	7″ × 7″ × 33 ,,	10	3·0	30	90	
Top girder behind armour .	8″ × 6″ × 6″ × 34 ,,	10	11·3	113	1280	
2nd ,, ,, ,,	8″ × 6″ × 6″ × 34 ,,	10	7·5	75	560	
Top angle Bhd. mid. to main deck	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 10 ,,	3	15·8	47	740	
Bottom ,, ,, ,,	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 10 ,,	3	9·4	28	270	
Top strake ,, ,, ,,	3·7′ × 14 ,,	16	14·0	224	3140	220
Bottom ,, ,, ,,	3·4′ × 20 ,,	20	10·9	218	2380	230
Middle deck (flat)	26·5′ × 40 ,,	318	9·2	2926	26930	
,, sloping top thickness	13·5′ × 60 ,,	243	6·5	1580	10280	9620
,, ,, bottom ,,	14·8′ × 40 ,,	178	6·4	1139	7290	8720
Inner girdle, top angle . .	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 10 ,,	3	9·0	27	240	
,, bulkhead, top plate . .	5·8′ × 12 ,,	21	6·3	132	830	700
Wing ,, ,, angle . .	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 10 ,,	3	9·0	27	240	
,, ,, ,, strake .	5·8′ × 12 ,,	21	6·4	134	860	700
,, ,, 2nd ,, .	4′ × 12 ,,	14	2·0	28	60	220
Inner bottom angle to mid. deck	6″ × 6″ × 28 ,,	8	3·9	31	120	
,, ,, top strake . .	3·9′ × 14 ,,	16	2·0	32	60	250
Outer ,, angle to mid. deck .	6″ × 6″ × 37·5 ,,	11	2·0	22	40	
,, ,, P strake . . .	2·1′ × 35 ,,	22	1·0	22	20	100
Cover plate to armour . .	1·5′ × 14 ,,	6	2·0	12	20	
Strap to 6″ backing . . .	1′ × 35 ,,	11	19·3	212	4100	
,, 12″ ,, ...	1′ × 35 ,,	11	11·5	127	1460	
,, 12″ ,, ...	1′ × 35 ,,	11	6·8	75	510	
Angle, middle deck to casing .	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 12 ,,	4	9·3	37	340	
,, main ,, ,, .	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 12 ,,	4	16·3	65	110	
,, upper ,, ,, .	$3\frac{1}{2}$″ × $3\frac{1}{2}$″ × 12 ,,	4	24·3	97	2360	
Casing coaming, middle deck .	18″ × 25 ,,	11	9·0	99	890	
,, ,, main ,, .	18″ × 25 ,,	11	16·0	176	2820	
,, ,, upper ,, .	18″ × 25 ,,	11	24·0	264	6330	
,, middle to main ,, .	6·4′ × 20 ,,	38	12·6	479	6040	1560
,, main to upper ,, .	7′ × 14 ,,	29	20·0	580	11600	1420
		2271		34200	650110	44730
			$\frac{1}{12}$ × 44730		3730	
				Total	653840	

MOMENT OF INERTIA.

Trial neutral axis assumed to be 20 feet above base.

PORTION BELOW ASSUMED NEUTRAL AXIS.

Alternative correction for rivet holes.

Alternatively the correction for rivet holes is made in the moment of inertia by reducing A, Ay, and I for the half in tension by $\frac{2}{11}$. Thus for hogging, in the example—

	A	Ay	I
Above N.A. $\times \frac{9}{11}$	1,858	28,000	535,000
Below N.A. . .	1,373	21,700	382,000
	3,231	6,300	917,000

N.A. above that assumed $= 6{,}300/3{,}231 = 1\cdot95$ ft.

Moment of inertia $= 917{,}000 - (6{,}300)^2/3{,}231 = 904{,}000$.

The new y is found and the stresses calculated as before except that the factor $\frac{11}{9}$ is omitted.

The resulting stresses are usually within 5 per cent of those found by the other method.

Stresses allowable.

The conventional method of determining the stresses greatly exaggerates them, particularly in large ships.

In ships about 400′ long, or less, allow 6 tons per square inch; 8 is permissible, for portions in tensions only, where high tensile steel is used. In larger ships 8 tons (compression) and 10 tons (tensile with high tensile steel) have been taken.

STRESS DUE TO SHEARING.

The shearing force on the hull is greatest at about one-quarter of the length from either end, and is approximately one-seventh to one-eighth of the displacement. It can be determined exactly from the curves of shearing force (fig. 211).

The shearing stress on the side plating and edge rivets is found by the method described on p. 332.

EFFECT OF CONTINUOUS SUPERSTRUCTURE.

Let A = area of original section of ship in square inches.
a = area added in the form of superstructure in square inches.
h = height above original neutral axis at which a may be supposed concentrated, in feet.
I = original moment of inertia of section in (inches $\times$ feet)^2.
y = original height in feet of top deck about neutral axis.

New moment of inertia $= \mathrm{I} + \dfrac{\mathrm{A}ah^2}{\mathrm{A} + a}$

New distance 'y' = distance of superstructure above new N.A. $= \mathrm{A}h/(\mathrm{A}-a)$. In order that the stress on the upper part of structure shall be reduced, the area added a must be greater than $\mathrm{A} \cdot \dfrac{h-y}{y} \cdot \dfrac{\mathrm{I}}{\mathrm{I}+\mathrm{A}h^2}$ This quantity is greatest when $h = y + \sqrt{y^2 + \mathrm{I}/\mathrm{A}}$; the minimum effective added area is then equal to $\mathrm{I}/2y(y + \sqrt{y^2 + \mathrm{I}/\mathrm{A}})$.

MECHANICAL POWERS.

THE power applied and the weight lifted are directly proportional to the distances moved through by each body in a given time.

- W = weight to be raised.
- P = power applied.
- D = distance of power from fulcrum.
- d = distance of weight from fulcrum.
- n = number of movable pulleys.
- L = length of inclined plane and wedge.
- H = height of inclined plane.
- C = circumference described by P.
- t = thickness of wedge.
- S = distance moved through by P.
- s = distance moved through by W.
- R = resistance to wedge.
- p = pitch of screw.

GENERAL FORMULÆ FOR ALL THE POWERS.

$$W = \frac{SP}{s} \qquad P = \frac{Ws}{S} \qquad S = \frac{Ws}{P} \qquad s = \frac{SP}{W}$$

THE LEVER AND WHEEL AND AXLE.

$$W = \frac{PD}{d} \qquad P = \frac{Wd}{D} \qquad D = \frac{Wd}{P} \qquad d = \frac{PD}{W}$$

FIG. 212.

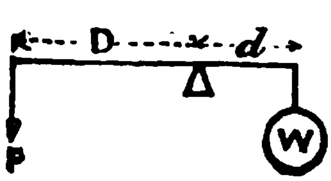


FIG. 213.

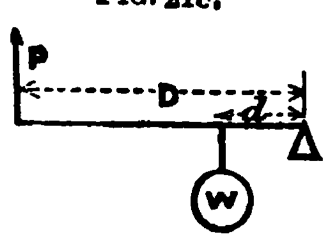


FIG. 214.

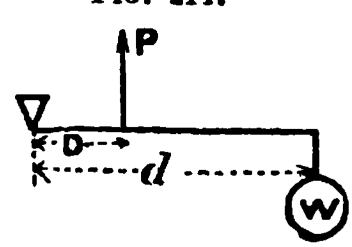
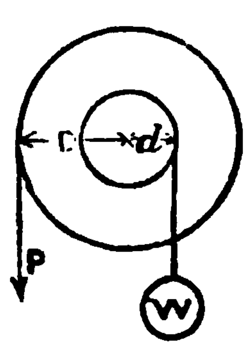


FIG. 215.



The Pulley.

$$W = 2Pn \qquad P = \frac{W}{2n}$$

Fig. 216.

ONE MOVABLE PULLEY

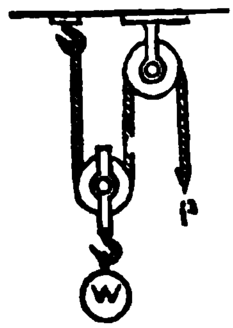
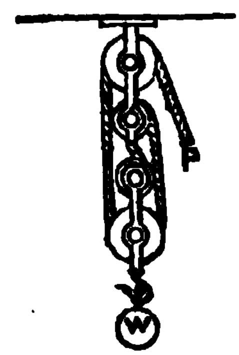


Fig. 217.

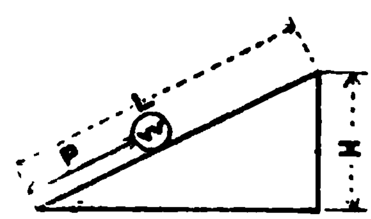
TWO MOVABLE PULLEYS.



Note.—For revolutions of wheels see p. 362.

The Inclined Plane.

Fig. 218.

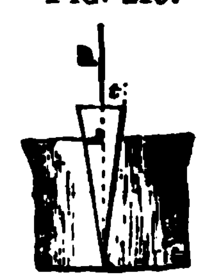


$$W = \frac{PL}{H} \qquad P = \frac{WH}{L}$$

$$H = \frac{PL}{W} \qquad L = \frac{WH}{P}$$

The Wedge.

Fig. 219.



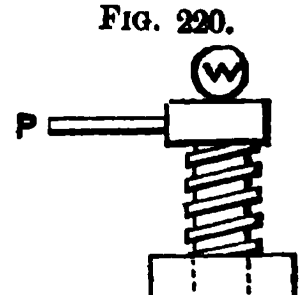
$$R = \frac{PL}{t}$$

$$P = \frac{Rt}{L}$$

$$t = \frac{PL}{R}$$

The Screw.

Fig. 220.



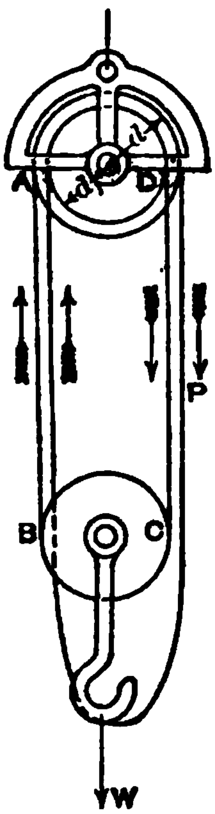
$$W = \frac{PC}{p} \qquad P = \frac{Wp}{C}$$

$$p = \frac{PC}{W} \qquad C = \frac{Wp}{P}$$

Note.—One-third more power than is obtained by the foregoing formulæ is generally allowed, in order to overcome the resistance due to friction, &c., weight and power being in equilibrium.

DIFFERENTIAL PULLEY.

FIG. 221.



A *Differential Pulley* consists of two blocks (see fig. 221). The upper block contains two sheaves of slightly different diameters, secured so as to revolve together. A chain is wound on the blocks as shown, the blocks having projections on their rims to fit the chain and prevent slipping.

Suppose the upper block makes one revolution: Then the length of loop ABCD is shortened by a length = circumference large sheave, and the loop is lengthened = circumference of small sheave.

Circumference of large sheave $= 2\pi d$,
" " small sheave $= 2\pi d_1$;

$\therefore$ Difference in length of loop $= 2\pi(d - d_1)$,
and the weight will be raised $\pi(d - d_1)$.

If P = force acting on chain, friction neglected, for one revolution of wheel P moves $2\pi d$;

$$\therefore \text{P} \times 2\pi d = \pi(d - d_1)\text{W}, \text{ and P} = \frac{d - d_1}{2d}\text{W}.$$

PULLEYS WITH FRICTION.

$$\text{P}s = \text{W}s + k\text{W}s + p's,$$

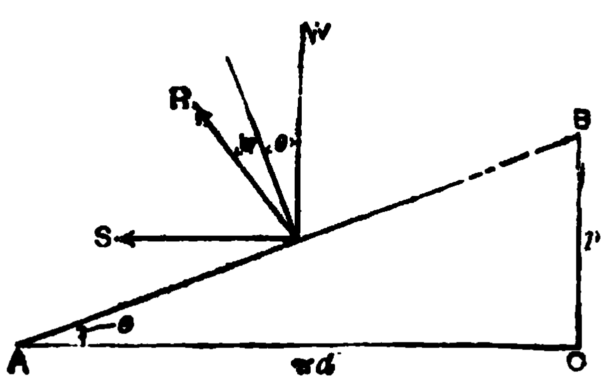
where p' and k are constants which can be determined for every system of pulleys by two experiments.

If the weight to be lifted is very large, p' can be neglected; if very small, k can be neglected. *

EFFICIENCY OF SCREWS.

Efficiency of Screws.—Let AB be one turn of the screw developed, then BC = pitch, and AC = circumference of screw,

FIG. 222.



W = weight lifted, R = reaction of screw thread. When R makes an angle ϕ with the normal = angle of repose, coefficient of

* A rough rule is to assume the tension of the rope to be diminished by 5 or 10 per cent. after each turn round an ordinary sheave. See example on p. 298.

friction $=\mu$. Now R is caused by the power applied to turn the screw; $\therefore$ its vertical component $=$ W, and its horizontal component S is such that if P $=$ moment of force used, $P = S \times \frac{d}{2}$;

$$\therefore P = \frac{Rd}{2}\sin(\theta+\phi), \text{ and } W = R\cos(\theta+\phi).$$

Work done by power in one revolution $= P + 2\pi = R\pi d\sin(\theta+\phi)$.

Work done on weight $= Wp = Rp\cos(\theta+\phi)$.

$$\text{Efficiency} = \frac{\tan\theta}{\tan(\theta+\phi)}.$$

This is a maximum when $\theta = 45° - \frac{1}{2}\phi$.

Then taking $\operatorname{Tan}\phi = 2\operatorname{Tan}\frac{\phi}{2}$, we get

$$\text{Maximum efficiency} = \left(\frac{1-\frac{1}{2}\mu}{1+\frac{1}{2}\mu}\right)^2$$

Conversely, if action be reversed,

$$\text{Efficiency} = \frac{\tan(\theta-\phi)}{\tan\theta}$$

For an irreversible screw θ must be less than ϕ. In screw steering gear and W.T. door screws, which should be just irreversible, θ is made ·08 or $4\frac{1}{2}$ degrees, giving a pitch equal to about 4 mean (pitch) diameters.

The thickness of a square thread is usually one-half the pitch; the depth is about $\frac{18}{40}$ pitch. In the "Acme" screw thread the longitudinal section is trapezoidal, the depth being $\frac{1}{2}$ pitch $+$ ·01″, the tip thickness ·3707 pitch, and the angle subtended between the two facing sides 29°. The bearing pressure on the threads in the direction of the axis when transmitting motion varies from 200 to 1,000 lb. per sq. in., depending on the lubrication.

The proportions of standard (Whitworth) V-screw threads are given in pp. 533–5; in the formulæ above for efficiency change $\tan\phi$ to $\tan\phi\cos\theta\sec\frac{\alpha}{2}$ for V-threads of angle α; for standard threads of small pitch this virtually increases ϕ by about 12 per cent.

The Sellers' thread (U.S.A.) consists of equilateral triangles of depth $d =$ pitch $\times \sqrt{3}/2$ or ·866 pitch. The tips and roots are flattened $\frac{1}{8}d$ from the vertices, so that the actual depth of thread is $\frac{3}{4}d$.

BELT GEARING.

Length of Crossed Belts.—If two pulleys of diameters D and d distant c apart from centre to centre, be connected by a crossed belt, the total length of the belt =

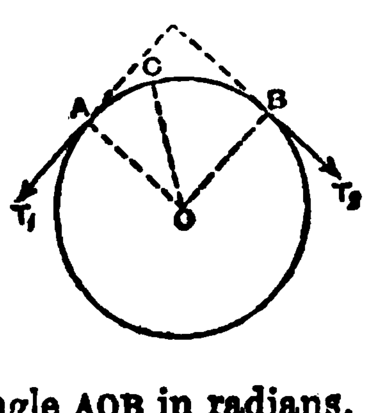
$$\left(\frac{\pi}{2} + \sin^{-1}\frac{D+d}{2c}\right)(D+d) + \sqrt{4c^2-(D+d)^2}.$$

This length is constant provided that the distance between the centres and also the sum of the diameters are constant. In designing speed cones for a lathe, the same belt will drive equally well on all if the sum of the diameters of each pair of pulleys be the same.

Length of Open Belts.—No simple exact rule can be given, but the following, though approximate, is generally accurate enough for practical purposes. Let one pair of pulleys have diameters D_1 and d_1. It is required to find the diameters of another pair of pulleys of different ratio, but driven by the same belt. Treat them first as if the belt were crossed, and find the diameters D_2 and d_2 of a second pair, so that $D_2+d_2=D_1+d_1$. Then calculate $(D_1+d_1)+\frac{(D_1-d_1)^2-(D_2-d_2)^2}{4\pi C}$, and taking this expression as the sum of the two required pulleys, and D_2-d_2 as the difference, recalculate D_2 and d_2, which will be the diameters required.

Resistance to Slipping.—A and B (fig. 223) are the points where belt leaves pulley T_1 and T_2 are the tensions of belt at A, B when on the point of slipping.

FIG. 223.



If θ = the angle AOB in radians.
μ = coefficient of friction between belt and pulley.
$e = 2{\cdot}718$.

$$T_2/T_1 = e^{\mu\theta}.$$

$$\text{or } \log_{10}(T_2/T_1) = {\cdot}434\,\mu\theta.$$

$$= \frac{\mu}{132} \times \text{angle AOB in degrees.}$$

Greatest Value of the Ratio of Tensions on Light and Slack Sides of Belting from Equation I.

Angle embraced by Belt $=\theta$			Ratio of Tensions $=k$			
In Degrees	In Circular Measure	In Fraction of Circumference	$\mu=0{\cdot}2$	$\mu=0{\cdot}3$	$\mu=0{\cdot}4$	$\mu=0{\cdot}5$
30	·524	·083	1·110	1·170	1·233	1·299
45	·785	·125	1·170	1·266	1·369	1·481
60	1·047	·167	1·233	1·369	1·521	1·689
75	1·309	·208	1·299	1·481	1·689	1·924
90	1·571	·250	1·369	1·602	1·874	2·193
105	1·833	·319	1·443	1·733	2·082	2·500
120	2·094	·334	1·521	1·875	2·312	2·851
135	2·356	·375	1·602	2·027	2·565	3·247
150	2·618	·417	1·689	2·194	2·849	3·702
165	2·880	·458	1·778	2·372	3·163	4·219
180	3·142	·500	1·875	2·566	3·514	4·808
195	3·403	·541	1 975	2·776	3·901	5·483
210	3·665	·583	2·082	3·003	4·333	6·252
240	4·188	·666	2 311	3·514	5·340	8·119
270	4·712	·750	2·566	4·112	6·589	10·55
300	5·236	·833	2·849	4·808	8·117	13·70

Let P = resistance at circumference of driven pulley, then $P = T_2 - T_1$; H = horse-power transmitted, and V = velocity of belt in feet per minute; then $PV = 33000\,H$, and $\therefore\ T_2 - T_1 = \dfrac{33000\,H}{V}$.

If N = number of revolutions of pulley per minute, d = diameter of pulley in inches; then velocity of pulley $= \dfrac{\pi d N}{12} = V$;

$$T_2 - T_1 = \frac{33000\,H \times 12}{\pi d N} = \frac{396000\,H}{\pi d N} = \frac{126000\,H}{d N}$$

The coefficients of friction between belt and pulley are about ·48 with leather belt on wood pulley, ·28 (dry) or ·38 (wet) with leather belt on iron pulley, and ·5 with hemp rope on wooden pulley. Take ·3 in general.

The speed of main belting should vary between 3,000 and 4,000 feet per minute. At high speeds both tensions are increased by centrifugal force; this increase is 35 lb. per square inch at 3,000 velocity, and it varies as the square of

the speed. This provides a limit to the efficient speed at which belting may be driven; for both T_2 and T_1 in the above equations are correspondingly reduced.

The thickness of a single belt is about $\frac{7}{32}''$; of a double belt $\frac{3}{8}''$ to $\frac{1}{2}''$.

The width varies from about 32 (small) to 70 (large) times the thickness.

The weight of 1 foot of belting, 1 square inch in section, is about ·45 lb.

The maximum working stress is 320 lb. per square inch for single belts and 240 lb. per square inch for double belts.

The convexity of the pulley should be $\frac{1}{16}''$ up to $6''$ width, $\frac{3}{32}''$ up to $12''$, and $\frac{1}{8}''$ beyond.

Approximate creep of belts is $2\frac{1}{2}$ to 3 per cent maximum; i.e. this is the excess speed of the driving over that of the driven pulley.

Approximate minimum pulley diameters for durable running.

(Mr. H. J. Spooner.)

Thickness of belt in 32nds inch . .	4	5	6	7	8	9	10	11	12	13	14	15	16
Diameter of pulley in inches . .	3·9	6·1	8·8	12	15·7	20	24·5	29·5	35	41	48	55	63

SIZE OF BELT REQUIRED.

k = ratio of tensions (see table on p. 358).

V = linear speed of belt in feet per minute $= \pi d N/12$.

H = horse-power transmitted.

f = working stress of belt in lb. per square inch (see above).

A = sectional area of belt in square inches.

$$H = \frac{1}{33{,}000} \cdot \frac{k-1}{k} \cdot VA\left\{f - 3 \cdot 9\left(\frac{V}{1{,}000}\right)^2\right\}.$$

Ex.—Find the area of belting required to transmit 25 H.P. at 4,000 feet per minute. $\theta = 165°$; $\mu = \cdot 3$. Take $f = \cdot 320$. From table $k = 2 \cdot 37$.

$$25 = \frac{1}{33{,}000} \times \frac{1 \cdot 37}{2 \cdot 37} \times 4{,}000\,A\,(320 - 62): \text{ whence } A = 5 \cdot 5$$
square inches.

Table of Work Done by Men and Animals. (*From Twisden's 'Practical Mechanics.'*)

Nature of Labour	Daily Duration of Work in Hours	No. of Units of Work per Day	No. of Units of Work per Minute	Weight Raised, or Mean Pressure, in Lbs.	Velocity in Feet per Minute
1. *Raising Weights Vertically.*					
A man mounting a gentle incline or ladder without burden—i.e. raising his own weight	8·0	203,200	4,230	145	29
Labourer raising weights with rope and pulley, the rope returning without load	6·0	563,000	1,560	40	39
Labourer lifting weights by hand	6·0	531,000	1,480	44	34
Labourer carrying weights on his back up a gentle incline or up a ladder, and returning unladen	6·0	406,000	1,130	145	8
Labourer wheeling materials in a barrow up an incline of 1 in 12, and returning with empty barrow	10·0	313,000	520	130	4
Labourer lifting earth with a spade to a mean height of $5\frac{1}{4}$ feet	10·0	281,000	470	6	78
2. *Action on Machines.*					
Labourer walking and pushing or pulling horizontally	8·0	150,000	3,130	27	116
Labourer turning a winch . .	8·0	1,250,000	2,600	18	144
Labourer pushing and pulling alternately in a vertical direction	8·0	1,146,000	2,390	11	216
Horse yoked to a cart and walking	10·0	15,688,000	26,150	150	175
Horse yoked to a whim gin .	8·0	8,440,000	17,600	100	175
Do. do., trotting . . .	4·5	7,036,000	26,060	$66\frac{2}{3}$	391

One man can lift with both hands 236 lbs.

" " " support on his shoulders 330 lbs.

A man's strength is greatest in raising a weight when his weight is to that of his load as 4 is to 3.

Note.—In the above table the unit of work is taken at a pressure of 1 lb. exerted through 1 foot.

TABLE GIVING THE USEFUL EFFECT OF AGENTS EMPLOYED IN THE HORIZONTAL TRANSPORT OF BURDENS. (*From Twisden's 'Practical Mechanics.'*)

AGENT	Duration of Daily Work	Useful Effect Daily	Useful Effect per Minute	Weight Transported in Lbs.	Velocity in Feet per Minute
Man walking on a horizontal road without burden—that is, transporting his own weight	10·0	25,398,000	42,330	145	292
Labourer transporting material in a truck on two wheels, returning with it empty for a new load	10·0	13,025,000	21,710	220	99
Do. do., with a wheel-barrow	10·0	7,815,000	13,030	130	160
Labourer walking with a weight on his back	7·0	5,470,000	13,030	90	145
Labourer transporting materials on his back, and returning unburdened for a new load	6·0	5,087,000	14,100	145	97
Do. do., on a hand-barrow	10·0	4,298,000	7,160	110	65
Horse transporting material in a cart, walking, always laden	10·0	200,582,000	334,300	1,500	223
Do. do., trotting	4·5	90,262,000	334,300	750	44
Do. do., transporting materials in a cart, returning with the cart empty for a new load	10·0	10,940,800	182,350	1,500	121
Horse walking with a weight on his back	10·0	34,385,000	57,310	270	212
Do. do., trotting	7·0	32,072,000	76,410	180	424

Note.—The useful effect in the above table is the product of the weight in lbs. and the distance in feet.

UNIVERSAL (HOOKE'S) JOINT.

For sketch of joint, see p. 549.

θ = angle between the axes of shafts.

R = ratio of the angular velocities.

R varies between sec θ and cos θ; attaining each value twice during a complete revolution.

In practice θ does not usually exceed 35°; R then varies between 1·22 and ·819.

Hand Cranes.

P = power applied to handle in lbs.
D = diameter of circle described by handle in inches.
W = weight to be lifted in lbs.
N = number of revolutions of handle.
n = number of revolutions of barrel.
d = diameter of barrel in inches.
l = length of handle in inches.

$$d = \frac{\mathrm{DPN}}{n\mathrm{W}} \qquad \frac{\mathrm{N}}{n} = \frac{\mathrm{W}d}{\mathrm{DP}} \qquad \mathrm{D} = \frac{\mathrm{W}dn}{\mathrm{PN}} \qquad \mathrm{W} = \frac{\mathrm{DPN}}{dn}$$

$$\mathrm{P} = \frac{\mathrm{W}dn}{\mathrm{DN}} \qquad l = \frac{\mathrm{W}dn}{2\mathrm{PN}} \qquad n = \frac{2\mathrm{PN}l}{\mathrm{W}d}$$

Note.—The ordinary height of handle above ground is 36 inches. Diameter of circle described by handle, 32 inches Power imparted by one man, from 15 to 20 lbs.

Steam Cranes.

S = speed of piston in feet per minute.
D = diameter of main drum in feet.
W = load to be lifted.
N = number of revolutions of main drum per minute.
P = pressure on one piston.
s = speed of main drum in feet.
n = number of revolutions of crank shaft per minute.
l = length of stroke in feet.
d = diameter of piston in inches.
p = pressure of steam in lbs. per square inch.

$$\mathrm{S} = 2nl \qquad s = 3{\cdot}1416\mathrm{ND} \qquad \mathrm{P} = {\cdot}7854pd^2$$

$$\mathrm{W} = \frac{nlpd^2}{\mathrm{ND}}$$

Velocity of Pulleys.

V = velocity of driving pulley.
D = diameter of driving pulley.
v = velocity of driven pulley.
d = diameter of driven pulley

$$\mathrm{D} = \frac{vd}{\mathrm{V}} \qquad d = \frac{\mathrm{DV}}{v} \qquad \mathrm{V} = \frac{dv}{\mathrm{D}} \qquad v = \frac{\mathrm{DV}}{d}$$

The final velocity of any number of pulleys

$= \dfrac{\mathrm{V} \times \mathrm{D} \times \mathrm{D}' \times \mathrm{D}'' \text{ \&c.,}}{d \times d' \times d'' \text{ \&c.,}}$ where D, D′, D″, &c., are the diameters of the driving wheels or pulleys, and d, d', d'', &c., the diameters of the driven pulleys.

Coefficients of Friction.	Coefficient of Friction.	
	From	To
Materials (dry).		
Metal on metal	·10	·30
Wood on metal	·10	·60
Wood on wood	·10	·70
Leather on metal . . .	·25	·60
Leather on wood . . .	·25	·70
Metal on stone	·25	·50
Stone on stone	·40	·75
Ice on ice	·018	·028
Steel on ice	·014	·027
Hemp on oak	about ·53	
Materials (lubricated).		
Metal on metal	·009	·10
Wood on metal	·02	·10
Wood on wood (see also p. 377)	·033	·10
Leather on metal . . .	·12	·25
Hemp on wet oak . . .	about ·33	
Ball-bearing races (Goodman).		
Cylindrical race . . .	·0012	·0018
Thrust—flat race . . .	·0018	·0012
One flat race, one V-race .	·0018	
Two V-races	·0055	

Note.—Under forced lubrication the friction is further diminished, the coefficient being found to vary with speed and temperature.

Friction of journals and pivots.

D = diameter in inches (larger diameter for pivots).
d = smaller diameter for pivots in inches.
W = load on journal or thrust on pivot in lb.
M = frictional moment in inch-lb.
H = horse-power lost.
B = British thermal units generated per minute.
N = revolutions per minute.
μ = coefficient of friction.
$H = MN/63{,}000$; $B = 42{\cdot}5\ H$.

Loose journal $M = \frac{1}{2}\mu WD$.
Tight new journal $M = {\cdot}78\,\mu WD$.
Worn journal $M = {\cdot}64\,\mu WD$.
New conical pivot, angle $2a$, $M = \frac{1}{3}\mu W \operatorname{cosec} a\,(D^3 - d^3)/(D^2 - d^2)$.
Worn ,, ,, $M = \frac{1}{4}\mu W \operatorname{cosec} a\,(D + d)$.
Flat pivot (new) $M = \frac{1}{3}\mu WD$.
Flat pivot (old) $M = \frac{1}{4}\mu WD$.

NOTES ON STEERING.

Terms used with reference to the tiller :—

Helm *a-starboard*, or inclined towards the right.	Means that rudder is *a-port*, or inclined towards the left.
Helm *a-port*, or inclined towards the left.	Means that rudder is *a-starboard*, or inclined towards the right.
Helm *a-lee*, or inclined to leeward.	Means that rudder is *a-weather*, or inclined to windward.
Helm *a-weather*, or inclined windward.	Means that rudder is *a-lee*, or inclined to leeward.

Steering Indicator.—Tiller and indicator should move the same way; rudder, wheel, and ship's head should move the same way, and opposite, of course, to tiller and indicator.

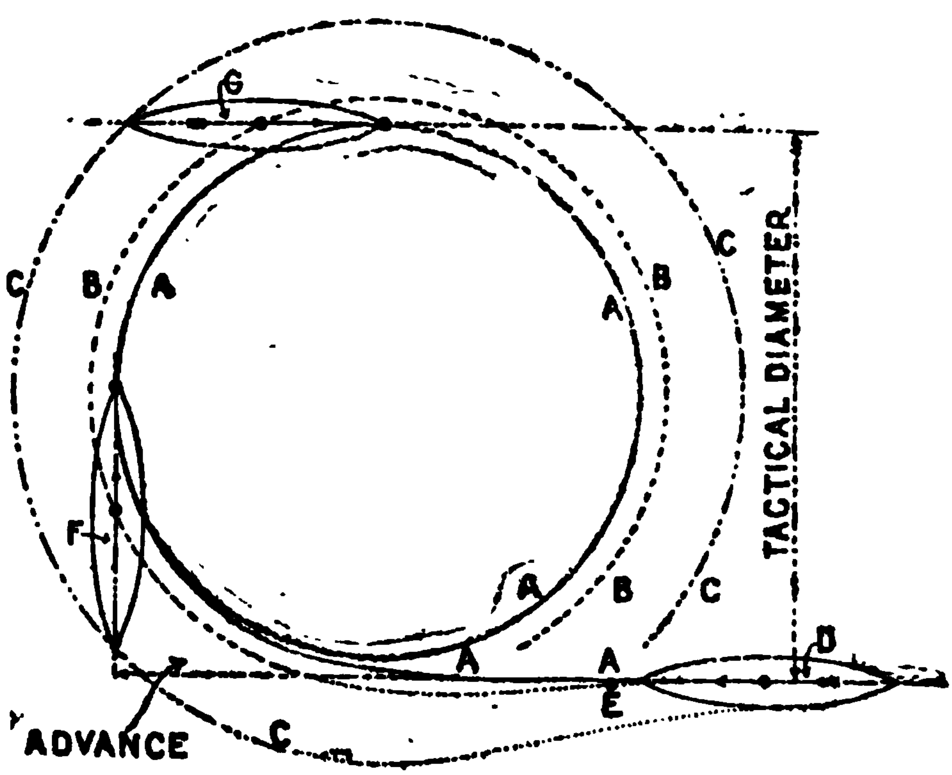
Four features chiefly affect the readiness of a ship to answer helm: (1) time occupied in putting helm hard over; (2) pressure on the rudder when hard over; (3) moment of inertia of ship about vertical axis passing through the centre of gravity; (4) moment of resistance to rotation.

For good steering it is also necessary that there are no eddies at the stern, and that the water flows steadily past the ship, so that the fairness and fineness essential for speed are also necessary for good steering.

PATH WHEN TURNING.

Fig. 224 shows the path described by a ship whose rudder is put over; BBB . . . is the path of the centre of gravity

FIG. 224.



of ship, CO . . . is that of the stern, and AA . . . is a line drawn to touch the middle line of the ship in its successive positions. The point of contact O of the ship with AA . . . is termed the *pivoting point*; it is usually situated very slightly abaft (in quick turning ships at) the bow. The ship thus appears to point inwards across its path except just at or near the bow.

The path of the ship differs very slightly from a circle; the *tactical diameter* is the maximum distance travelled perpendicular to the original direction; the *advance* is the total distance travelled in the original direction from the moment of putting over the helm.

STEERING DATA FOR WARSHIPS (FULL SPEED, 35° HELM).

Ship.	Length in feet.	Area of immersed longitudinal plane divided by area of rudder.	Advance in yards.	Tactical diameter in yards.	Tactical diameter divided by length.
Battleship *	490	37·5	490	440	2·7
,, ...	410	40·5	400	370	2·7
,, ...	400	45·2	440	500	3·7
Cruiser	490	48·4	480	600	3·7
,, ...	440	44·4	590	790	5·4
,, †	435	44·5	650	920	6·3
,, †	500	50·3	800	1120	6·7
,, ...	350	48·3	540	770	6·6
,, ...	320	33·5	350	380	3·6
T.B. Destroyer (27 knots)	270	40·0	390	550	6·1
,, (12 knots)			280	300	3·3

* Two rudders. † Stern not cut away.

INFLUENCE OF VARIOUS FEATURES ON STEERING.

Length.—In the above table, tactical diameter is expressed in terms of the length, though in very long ships this ratio tends to increase.

Rudder Area.—This is usually a proportion of that of the immersed middle line plane of the ship. The ratio is given above for warships; it is about 60 in many passenger and cargo ships, 20 in steamboats, 15 in yachts and sailing boats. In long narrow ships the area should be increased relatively to the size in order to maintain facility of turning.

Form of Rudder.—A narrow deep rudder develops *cet. par.* more pressure and requires a smaller force to handle than a wide shallow rudder. The rudder should always, therefore,

be as deep as possible; but the depth is limited in warships by the necessity of keeping the top well immersed. A rudder may be balanced to reduce the power required to control it; not more than 30 per cent of its area should lie before the axis, or there may be difficulty in bringing it back to the middle.

Form of Ship.—The resistance to turning is greatly diminished by cutting away the after deadwood (see table above). With unbalanced rudders this may reduce the deadwood pressure (which assists steering at small angles) to such an extent as to render ship rather unmanageable. In all cases it reduces the space required to turn, but in excess it may make vessel rather slow to answer helm.

Position of Rudder.—This should be as nearly as possible directly behind the screws so as to have the benefit of their race. Twin rudders utilize this and enable vessel to be steered from rest; the resistance of the ship, however, is at the same time slightly increased (see p. 162).

Speed.—This affects, in general, only the time of turning; the path is nearly the same at low as at high speeds. An exception is found in destroyers and similar ships whose rudders exhibit 'cavitation' at their highest speeds, thus increasing the space required for turning. In quick-turning vessels the speed after turning through 180° may sink to half or even one-third of its original amount.

Draught.—Increase of draught aft enlarges the circle, since the resistance to turning is augmented.

Screw Propellers.—By reversing the inner screw at the same time as when helm is applied in ships having more than one shaft, the tactical diameter may be reduced to about two-thirds its usual amount, but the time required for turning is increased. By stopping way on the ship, it is possible by manipulating the propellers to turn a vessel without helm about her own centre. When stopping, with both propellers reversed, the effect of helm is uncertain.

With a single right-handed screw, well immersed, the ship's head usually tends to turn to starboard, but the contrary may result if the screw breaks the surface of the water.

Helm Angle.—At reduced helm angles the space required for turning is increased. Approximately if 1 represents the space (tactical diameter or advance) with 35° of helm, then 1·4 is that for 20° and 2 for 10°. Usually nothing is gained by increasing helm beyond 35° or 40°.

Method of carrying out Turning Trials.

Throw out two buoys that are easily visible about 2 miles apart. The circles are turned round each buoy alternately; this enables the vessel to pick up her full speed before turning each time.

At two points A and B (fig. 225), usually on the upper deck at the middle line, sights are erected with quadrants so that the angles CAB, CBA, made by the buoy (C) can be measured. These sights may be of the form shown in fig. 226, where C is a batten hinged at A, carrying two upright wire sights S,S. At intervals a signal is given, and observers measure simultaneously the time, the angles at the quadrants, and

FIG. 225.

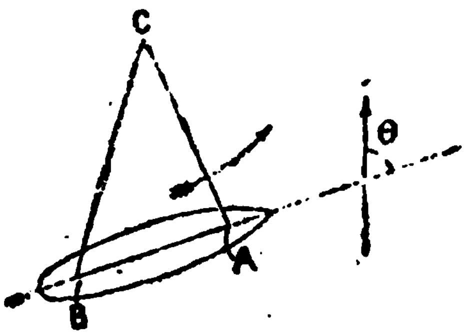
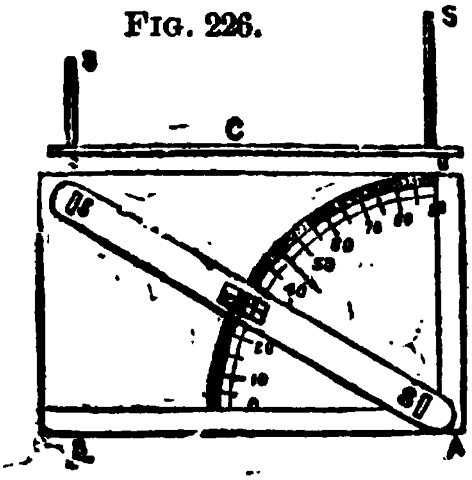


FIG. 226.



the angle (θ) made by the ship's head with a fixed bearing. Since the distance AB is known, this information enables the triangle ABC to be constructed and laid in its correct position for each reading. If this is done after turning through every four points (45°) from the original course, or oftener if desired, until 32 points are turned through and the original course regained, the path of any point of the ship (usually the C.G., assumed at mid-length, is selected) may be drawn in. The speed at any point may be roughly determined from the observed times.

On the completion of a warship these trials are carried out usually (*a*) at full speed, (*b*) at 12 knots, (*c*) with revolutions corresponding to 12 knots, but with the inner screw or screws reversed at the moment of putting over the rudder. In each case two circles are made, one to port and one to starboard.

Alternative method.—Instead of the buoy, a boat is used, from which the distance of the ship is determined either by measuring the masthead angle or by means of a range-finder. The time to take the observation is signalled from the ship. A second observer on the boat simultaneously measures the compass bearing of any fixed point (e.g. a mast) in the ship.

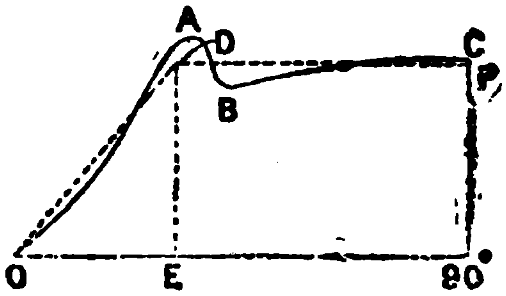
PRESSURE ON RUDDER.

If a rudder is held in a stream of water or, equally, is moved through still water, the normal pressure on it varies with the angle of inclination in the manner indicated in fig. 227.

It follows no simple mathematical law, but increases up to a 'hump' at A, then suddenly drops to B as the angle is slightly increased; finally, it increases slightly, attaining a

value at C (90°), which is usually less, but sometimes greater, than that at B. The simplest formula by which it may be approximately expressed in terms of the angle is that given by two straight lines OD, DF, of which DF is horizontal.

FIG. 227.



If α be the angle OE, and R the value of the ordinate DE, then

$$\text{normal pressure } P = R\theta/\alpha \text{ when } \theta \text{ is less than } \alpha.$$
$$= R \text{ when } \theta \text{ is greater than } \alpha.$$

The value of R in salt water is given by—

$$R = KAV^2$$

where R is in lb., A is the area in square feet, and V the velocity in feet per second. The constant K varies in salt water from 1·1 to 1·2, say 1·15 average, though in plates of extreme proportions it may be slightly greater. See also pp. 409 and 431.

The angle α where the pressure first attains a maximum varies with the shape of the plate. It is approximately as follows :—

Shape of Plate.	Angle α.	'K' for greatest pressure.	Corresponding angle.
Circle or square . . .	25°	1·5	37°
Ellipse or rectangle, horizontal side twice vertical . . .	28°	1·7	40°
Ellipse or rectangle, horizontal side half vertical . . .	23°	—	—
Ellipse or rectangle, horizontal side one-quarter vertical .	16°	—	—

Note.—The greatest pressure given in the right-hand columns is that at the 'hump'; this is unstable, and the pressure there is liable to fluctuate considerably. In the last two results the hump pressure is less than at 90°.

From this it is evident that the rudder pressure for the greatest angle of helm, usually 35°, may have a value of K as great as 1·2 or even more. On the other hand, this is considerably modified by the immediate diminution in the ship's speed on turning and by the reduction in the effective

helm angle caused by the lateral movement of the stern. From experiments made it appears that this reduces the coefficient to about one-half its value, rather less (40 per cent) at high speeds and rather more at low speeds, agreeing fairly well at 35° with the usual formula—

$$P = 1{\cdot}12\ AV^2 \sin\theta.$$

The speed V is greater than the speed of the ship by about 20% in twin-screw ships, and 30% in single or quadruple-screw ships where rudder is directly behind propeller.

Hence, finally, if P is in tons, A in square feet, and V_s the speed of the ship in knots, at 35° helm.

$P = AV_s^2/900$ for twin- or quadruple-screw ships with single rudder.

$P = AV_s^2/750$ for single-, triple-, or quadruple-screw ships (rudder directly behind screw).

$P = AV_s^2/3{,}000$ for ships going astern.

In the last formula V_s is the speed ahead, that astern being assumed $\frac{2}{3}$ V_s. Where associated with 'live-load' working stresses, these figures may be regarded as on the safe side.

Position of Centre of Pressure.

The distance of the centre of pressure from the leading edge of a rectangular rudder is ·2 × breadth at small angles of inclination, about ·3 × breadth at 15°, and about ·4 × breadth at 35°, except for wide short rudders, where the proportion becomes ·33. It is usually assumed to be $\frac{3}{8}$ breadth at 35°. See also p. 415.

To obtain the C.P. of a rudder with a curved outline, divide the surface horizontally into strips of equal depth. Find the C.P. of each strip, taking it to be at $\frac{3}{8}$ the mean breadth from the front edge. By adding the areas of the strips and their moments about a fixed vertical axis, the total area and moment are obtained; the distance of the C.P. abaft this axis is the quotient when the total moment is divided by the whole area.

When going astern substitute the after edge for the leading edge.

Strength of Rudder Head and Pintles.

Unbalanced rudders (fig. 228).—Assume the rudder discontinuous at the pintles. Find the reactions at A and B due to the pressure on the portion AB; that on B will generally be rather more than half the total. Treat similarly the pressure from B to C. Force on pintle B is the sum of the reactions due to the two portions; force on pintle C is usually about $\frac{3}{8}$ the pressure on the lower portion.

With several pintles proceed similarly. The lowest pintle takes about one-half the pressure taken by each of the others.

The bending moment on the head A is generally small. The twisting moment is equal to the rudder pressure multiplied by the distance of the centre of pressure abaft the axis.

Balanced rudders supported at the bottom.—The lower bearing usually takes about $\frac{3}{8}$ of the total pressure. Find twisting moment on the head as before; it is usually greatest when going astern. The bending moment on the head is uncertain, but it cannot exceed $\frac{1}{8}$ of the total pressure × depth.

FIG. 228.

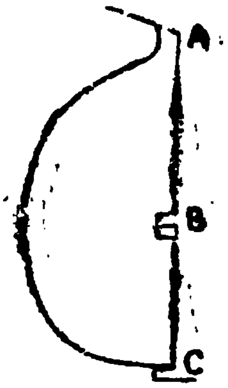
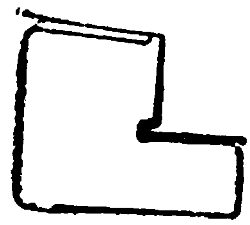


FIG. 229.



Balanced rudders (fig. 229) *supporting midway.*—The pressure on the pintle with average shapes of rudder is $\frac{4}{5}$ the whole pressure. The bending moment on the head is equal to the rudder pressure multiplied by $\frac{1}{12}$ the whole depth of the rudder.

Balanced rudders supported wholly inboard.—The bending moment on the head is equal to the rudder pressure multiplied by the depth of the centre of gravity below the lower edge of bearing.

Size of pintles.—If D = diameter of pintle in inches.
L = bearing depth of pintle in inches.
K = a constant varying from 2 to $2\frac{1}{2}$.

Pressure on pintle in tons = KLD.

Diameter of rudder head.

T = twisting moment in foot-tons.

f = stress allowable in material, expressed in tons per square inch.
= 5 for cast steel, 4 for forged iron, 3 for phosphor bronze.

D = diameter of rudder in inches.

$D^3 = 61\,T/f$.
= 12 T for steel.
= 15 T for iron.
= 20 T for phosphor bronze.

If there is a bending moment M in addition to the twisting moment, replace T by the equivalent moment $M + \sqrt{M^2 + T^2}$. In all balanced rudders calculate when going both ahead and astern and take the greater combined moment.

Note.—For low-speed ships or sailing ships, take an 'equivalent speed' which will represent the action of the waves. See British Corporation Rule below.

Example.—A twin rectangular rudder, hung wholly outboard, is 18 feet broad and 14 feet deep. Determine the size of the steel rudder head, if the rudder axis lies 6 feet abaft the leading edge. Speed of ship 21 knots; 4 screws.

(1) When going ahead, centre of pressure is $\frac{3}{8} \times 18$ feet or $6\frac{3}{4}$ feet abaft leading edge; that is $\frac{3}{4}$ feet abaft axis. Its distance below bearing would be about 8 feet.

Rudder pressure $= AV_s^2/750 = 18 \times 14 \times 21 \times 21/750 = 65$ tons.

Twisting moment $T = 65 \times \cdot 75 = 49$ foot-tons.

Bending moment $M = 65 \times 8 \quad = 520$ foot-tons.

Equivalent twisting moment $= M + \sqrt{M^2 + T^2} = 1040$ foot-tons.

(2) When going astern, centre of pressure is $6\frac{3}{4}$ feet abaft the after edge; that is $5\frac{1}{4}$ feet abaft the axis.

Rudder pressure $= AV_s^2/3000 = 16$ tons.

Twisting moment $= 16 \times 5 \cdot 25 = 84$ foot-tons.

Bending moment $= 16 \times 8 = 128$ foot-tons.

Equivalent twisting moment = 280 foot-tons, less than when going ahead.

Hence $D^3 = 12 \times 1040$ or $D = 23\frac{1}{4}$ inches.

British Corporation Rule for Size of Rudder Heads, etc.

D = diameter of head in inches.

R = distance in feet of centre of gravity of immersed area of rudder from centre line of pintles.

A = area of rudder up to L.W.L. in square feet.

V = maximum sea speed in knots.

$D = \cdot 26 \sqrt[3]{R A V^2}$ for steamers.

$D = 1 \cdot 26 \sqrt[3]{R A}$ for sailing vessels.

In the above formula take V at least 11 in vessels of 250 feet length and over, and at least 8 in vessels of 100 feet length, proportionately for intermediate lengths.

Thickness of Rudder Plate.

Length of Vessel.	Thickness of Single Plate (fortieths of an inch).	Thickness of Double Plates (fortieths of an inch).
100	25	12
200	30	14
300	35	16
400	40	18
500	45	20
600	50	20

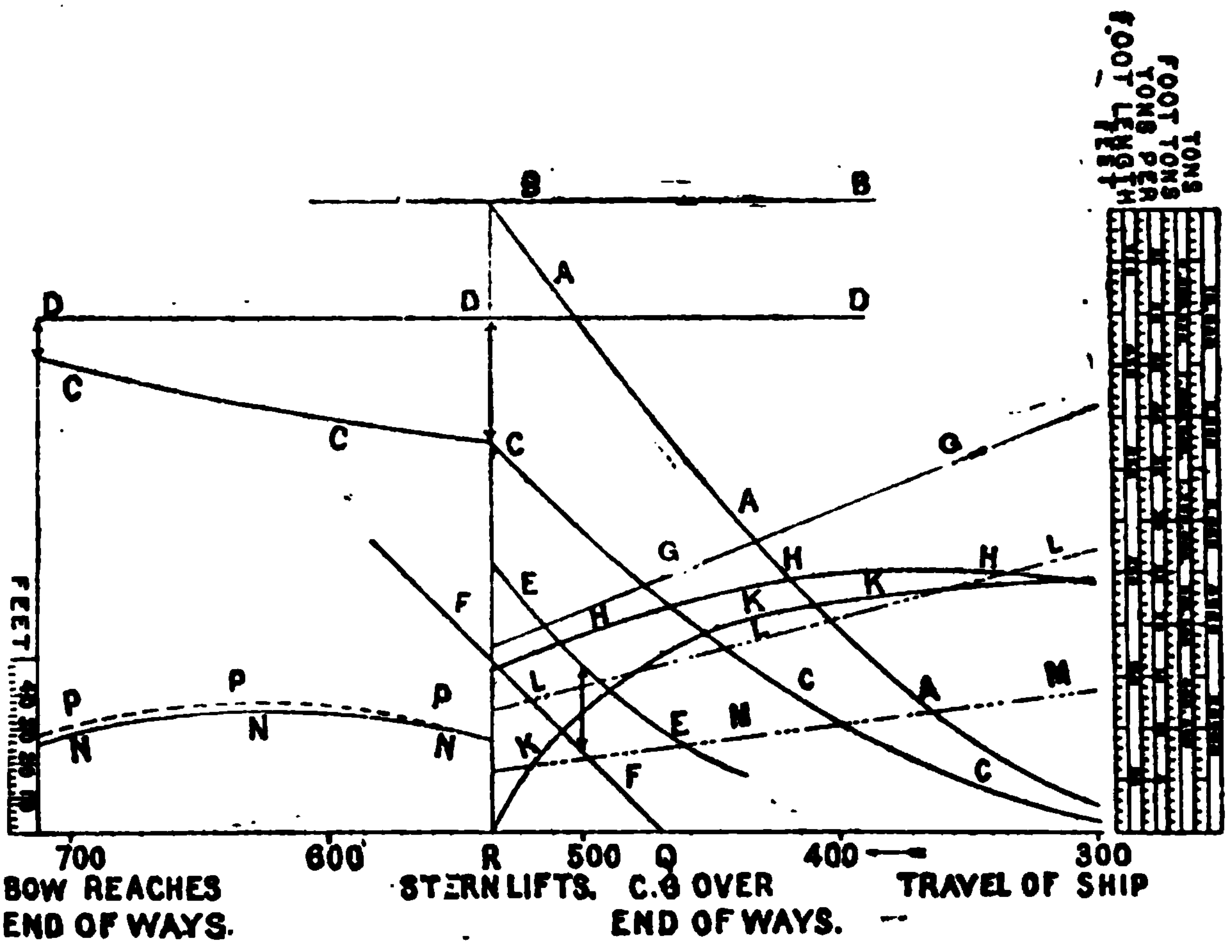
Gudgeons and Pintles.—Space of gudgeons not more than 4 feet in vessels 10 feet deep amidships, and 5 ft. 6 in. for vessels 40 feet deep; interpolate for other depths.

Depth of gudgeons to be not less than 75% diameter of stock (D); thickness $\cdot 275\,D$ if unbushed, and $\cdot 25\,D$ if bushed. Diameter of pintles $\cdot 5\,D$.

Steering Chains.—See p. 509.

LAUNCHING.

FIG. 180.



AA = moment of buoyancy about fore poppet (foot-tons).

BB = moment of weight about fore poppet (foot-tons).

CC = buoyancy (tons).

DD = weight (tons).

EE = moment of buoyancy about after end of ways (foot-tons).

FF = moment of weight about after end of ways (foot-tons).

GG = length of ways in contact (feet).

HH = mean pressure on ground ways (tons per foot length).

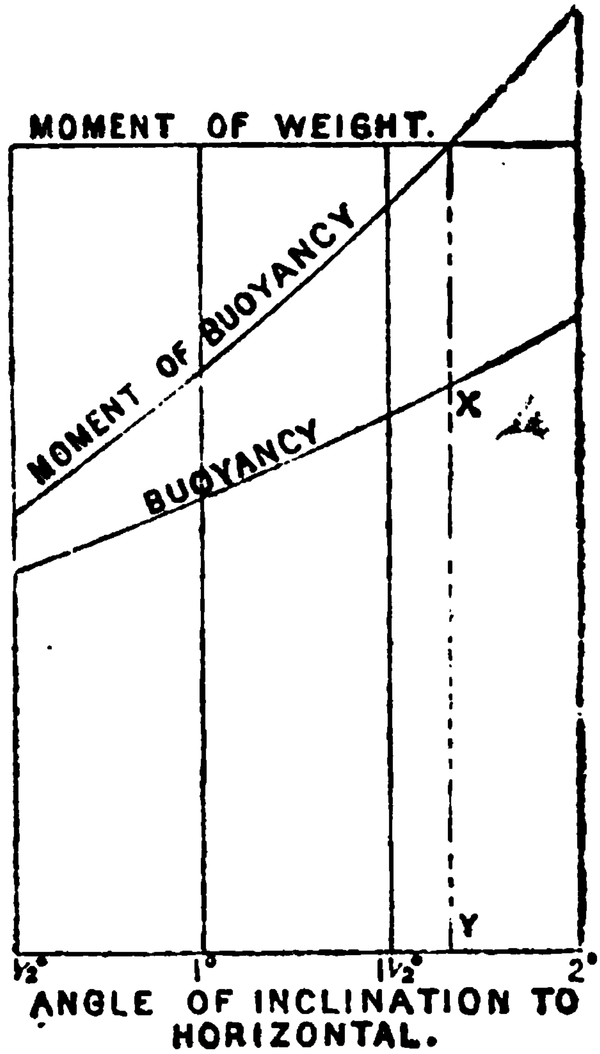
KK = position of resultant ground way pressure (distance from fore poppet in feet).

LL, MM = lines having ordinates equal to $\frac{2}{3}$ and $\frac{1}{3}$ those of GG.

NN = Depth of lowest point of cradle below water, speed of launch being assumed very slow.

PP = depth of lowest point, including allowance for speed of launch.

FIG. 231.



LAUNCHING CALCULATIONS.

The calculations usually made include the determination of the position where the stern lifts, the maximum pressure on fore poppets, and the liability to tip over the end of the ways. These are found from the curves AA, BB, CC, DD, EE, and FF (fig. 230).

In special cases it may be desirable also to find the amount of dredging necessary (from the draught aft), and the amount and distribution of the pressure on the ways up to the point of lift. These are found from the remaining curves in fig. 230.

Method of Procedure.—(1) Construct 'bonjean' curves, or curves of areas of sections up to the highest water-line likely to be found. With twenty-one ordinates it is sufficient to do this at alternate sections only.

(2) Estimate the draught at every section after running various distances, the greatest being slightly beyond the probable point of lift. This is done by calculating the draught at any two sections—say the fore and after poppets; on plotting them with a contracted longitudinal scale, the draughts at all other sections can be measured off.

Let D = depth of water over end of ways

A = length of ground ways up to fore poppet.

B = length of cradle (fore to after poppet).

C = height of camber on the length of ground ways (A).

H = height of keel at fore poppet above surface of ways.

x = distance run.

All in feet and decimals of a foot.

α = inclination of ship's keel at start.

β = mean inclination of ground ways expressed as a fraction (thus $\frac{5}{8}''$ to $1' = \frac{5}{96}$).

Then, radius (R) of ways = $A^2/8C$.

$$\text{Starting declivity} = \beta - \frac{A-B}{2R} = \beta - \frac{4C}{A^2}(A-B).$$

$$\text{Draught of ship at fore poppet} = D - H - (A - x)\left(\beta + \frac{4Cx}{A^2}\right).$$

$$\text{Draught at after poppet} = \text{Draught at fore poppet} + B\left(\alpha + \frac{8Cx}{A^2}\right).$$

Note.—Negative draughts denote height of keel above water.

(3) Using these draughts, read off the areas of the sections from the bonjean curves, and put them in a table. Then, using Simpson's rules, find the total displacement and the longitudinal centre of buoyancy. Thence plot the three curves (*a*) buoyancy (CC), (*b*) moment of buoyancy about fore poppet (AA), (*c*) moment of buoyancy about after end of ways (EE).

(4) Estimate approximately the weight and longitudinal C.G. of ship. This can be fairly readily done when the design information is available; in other cases judgment should be exercised as to what proportion of the final displacement will be launched. For battleships 40% is usual. In Trans. Inst. Nav. Arch., 1913, Mr. A. Hiley gives the following average launching displacements on a length of 400 feet: light craft and T.B.D., 1,000; sea-going T.B.D., 1,500; light cruisers, channel boats, 2,000; passenger boats, liners, cruisers, 2,500; cargo boats, liners, cruisers, 3,000; cargo boats, battleships, 4,000; heavy craft, barges, 5,000; ice-breakers and submarines, 6,000 tons. For other lengths vary displacement as the cube of length; for liners 600 feet take 10,000 tons, 700 feet 14,500 tons, 800 feet 20,000 tons, 900 feet 28,000 tons.

For the distance of the C.G. of ship abaft fore poppet, ·42 length is given as an average value.

(5) Plot the straight lines representing weight (DD, fig. 230), moment of weight about fore poppet (BB), moment of weight about after end of ways (FF).

(6) The intersection of curves AA and BB gives the point of lift, R; the difference between the corresponding ordinates of the curves CC and DD gives the weight on the fore poppets at that instant. The clearance between the curves EE and FF should be sufficient to obviate the possibility of tipping about the after end of ground ways.

Additional Investigations.—(7) The draught at the stern after lift is found as follows: Determine the draught at the fore poppet for various distances run, all beyond R (see formulæ above). For each run considered keep this draught and calculate the draughts at all sections when trimmed to various angles to the horizontal, e.g. ½°, 1°, 1½°, and 2°. Thence determine the buoyancy and its moment about the fore poppet at each angle, and plot them (fig. 231) on an angle base. The intersection of the latter curve with that of the moment of weight determines the balancing angle and the buoyancy *xy*. On plotting the latter in fig. 230 the left-hand portion of the curve CC may be completed; the difference between it and DD gives the weight on the poppets.

(8) The draught at the stern is easily calculated from the balancing angle, and is plotted in the curve NN. In a quick launch this draught might be exceeded owing to the inertia of the ship. It most cases it would be sufficient to allow 2-3 feet, depending on the size of the ship; PP can be set this distance beyond NN, the right hand being terminated by a line tangential to NN at the point of lift.

(9) The line GG represents the length of ways in contact before lifting; the intercept between DD and CC gives the total pressure on the ways. By division the mean pressure per foot length is obtained and plotted in curve HH.

The distribution of this pressure is calculated by dividing the difference between by the moment of buoyancy and weight about fore poppet (intercept between BB and AA) by the total pressure on the ways. This gives the distance of the resultant pressure on the ways from the poppet; it is plotted as KK. The straight lines LL, MM have ordinates respectively equal to ⅔ and ⅓ those of GG—the length of ways in contact. When KK crosses LL the maximum pressure is at the after end of ways, and is double the mean. Where KK is above LL the maximum pressure is more than double the mean, and the pressure is concentrated near the end of ways; the portion of the ship in wake of the after end of ways over this range may require extra shoring in order to withstand the concentrated pressure. Conversely where KK lies below MM, the pressure is concentrated near the fore poppet.

(10) The shearing force is usually greatest at the fore

poppet at the moment of lifting. Considerable shear forces also occur before and after this position; in large ships it may be advisable to calculate them for several amounts of travel. The force and stress are calculated by the usual methods (pp. 332, 346); if the factor of safety is less than 3, additional shoring should be provided.

(11) The bending moment is large (sagging) at the moment of lift; it is frequently also large (hogging) at a smaller travel. The curve of bending moment and the resulting stress are obtained by methods similar to those used for a ship on a wave (p. 346); the factor of safety should be at least 5. The decks should be riveted up sufficiently to withstand these stresses.

Launching Particulars for the 'Lusitania'.

(W. J. Luke, Esq., Trans. Inst. Nav. Arch., 1907.)

Displacement, 16,000 tons; declivity of ship, $\frac{7}{16}''$ to 1′; overhang at bow, 58′; overhang at stern (to aft perpendicular), 48′ 4″; length of cradle, 653′ 8″; breadth of cradle, 6′; pressure per square foot, 2·04 tons; length of ground ways, 795′ 6″; breadth of ground ways, 6′; mean declivity, ·51″ to 1′; camber, 1′ 4″; distance of centres of ways apart, 25′; length of slip, 760′; breadth, 87′ 6″; depth to shelter deck, 60′ $4\frac{1}{2}''$; load displacement at 32′ 6″, 36,840 tons.

In the *Mauretania*, a similar ship, the coefficient of friction was ·0232; maximum velocity, 14 knots; lubricant per 100 square feet—tallow 190 lb., train oil 8 lb., soft soap $14\frac{1}{2}$ lb.

The following data are given for a battleship launched at 7,300 tons, about 35% of the load displacement: Declivity of ways, $\frac{5}{8}\frac{5}{2}$ to a foot; camber, 7″ in 420 feet; length of ground ways, 510 feet; length of cradle, about 400 feet = ·8 × length of ship; weight per square foot, 2·47 tons; coefficient of friction, ·05; maximum speed shortly before lifting, 12 knots; temperature, 58° F.

General Notes.

The distance apart of ways between centres is equal to the breadth of ship divided by from 3 to $3\frac{1}{2}$.

STARTING DECLIVITIES AND COEFFICIENTS OF FRICTION (AVERAGE).

(A. Hiley, Esq., Trans. Inst. Nav. Arch., 1913.)

Launch Displacement in tons.	Approximate Length of Ship in feet.	Breadth of Launching Ways.	Pressure per sq. ft. on Sliding Ways.	Coefficient of Sticking Friction.		Extra Starting Slope in 32nd inches per foot.	Starting Declivity in 32nd inches per foot.	Decrease of Friction per increase of 1 ton per sq. ft. pressure.		Coefficient of Sliding Friction.	
				μ	In 32nd inches per foot.			μ	In 32nd inches per foot.	μ_1	In 32nd inches per ft.
100	100–150	9 in. to 1 ft.	1·0	·058	22	5	27	·005	1·5 to 2	·045	17
500	180–280	1 ft. 2 in.	1·3	·052	20	3·5	23·5	·005	1·5 to 2	·038	14·7
1,000	220–330	1 ft. to 2 ft.	1·4	·049	18·5	3	21·5	·005	1·5 to 2	·035	13·7
2,500	310–430	2 ft. to 3 ft.	1·5	·046	17·6	2·2	19·8	·004	1·5	·034	12·8
5,000	410–530	4 ft.	1·65	·044	16·8	2	18·8	·004	1·5	·031	12·1
10,000	550–660	5 ft. to 6 ft.	1·9	·041	15·5	2	17·5	·004	1·5	·028	10·7
15,000	680–750	6 ft.	2·15	·038	14·5	2	16·5	·0026	1·0	·025	9·6
20,000	760–820	6 ft. to 7 ft.	2·4	·036	13·6	2	15·6	·002	·8	·023	8·8
25,000	840–880	7 ft.	2·65	·034	13	2	15·0	·0018	·7	·021	8·0
30,000	900–930	7 ft. to 8 ft.	2·9	·033	12·5	2	14·5	·0016	·6	·021	8·0

For formula for starting declivity see par. 2 (above). See also p. 378.

The effect of camber on the ways is to reduce the distance run, to increase the fore poppet pressure, and to diminish the possibility of tipping.

The pressure on dogshores or holding arrangements is equal to the launching weight multiplied by the difference between the starting declivity and the coefficient of sliding friction. Adopting the data in the table above gives a force equal to about $\frac{1}{80}$ the launching weight in large ships.

The force required to draw a vessel up the ways is equal to the weight multiplied by the sum of the declivity and the greatest possible coefficient of friction.

The declivity of the ship is fixed in relation to that of the ground (height of keel blocks should be about 5 feet); it is conveniently $\frac{1}{32}''$ to a foot less than the starting declivity. With small declivities the stresses and pressures on poppets are diminished; but the distance run and the length of the ways are increased.

The information in the table on p. 377 applies to 55° F. temperature. At 80° F. decrease μ by 10%; at 40° F. add 5 or 10% more to the friction. In cold dry weather μ can be reduced by 10% by adding $\frac{1}{2}$ gallon of train oil per 100 square feet of ways. Grease assumed $\frac{1}{4}$ soft soap and $\frac{3}{4}$ tallow; for 100 square feet allow 100 lb. for 1,000-ton ship, 120 lb. from 2,000 to 10,000 tons, 140 lb. for 15,000 tons, 180 to 220 lb. for larger ships.

ARMOUR AND ORDNANCE.

Perforation of Armour.

w = weight of projectile in lb.
v = velocity at impact in feet per second.
D = diameter of projectile in inches.
t = thickness of *wrought iron* perforated in inches.

$$t^2 = \frac{wv^3}{D \log^{-1} 8\cdot841} \text{ (Tresidder);}$$

$$t^{1\cdot4} = \frac{wv^2}{D \log^{-1} 6\cdot355} \text{ (Gavre).}$$

The ratio $\frac{\text{thickness of wrought iron perforated}}{\text{thickness of armour perforated}}$ is termed the *figure of merit*. For cemented armour plates the figure of merit lies between 1·75 (thick plates) to about 2·5 (thin plates) when attacked by a capped armour-piercing shell. Against an uncapped shell add about ·6 to these figures.

The formula does not apply to plates more than 12″ in thickness; the resistance to perforation for thicker plates is proportionately small.

Oblique Perforation.—If θ be the angle between the axis of projectile and the normal to armour surface, the perforation is roughly equal to $t \cos \theta$ when θ is fairly small (i.e. up to 30°); for larger obliquities the perforation is smaller than that indicated by the formula.

Horizontal Armour.—It is usual to make thickness $\frac{1}{3}$ or $\frac{1}{4}$ of that which would be required in vertical armour to obtain the same degree of protection.

MOTION OF PROJECTILES.

For muzzle velocities of various types see pp. 380 etc.

Velocity.—At any range the striking velocity may be roughly determined by taking the velocity at the end of each 3,000 yards to be a certain percentage of that at the commencement of that distance. This percentage is about 90 for the largest guns, 85 for 12 and 9·2″ guns, and 75 for 6″ guns. Thus, in 6″ guns, if the muzzle velocity be 2,500 feet per second, after 3,000 yards it is $2{,}500 \times \cdot 75$ or 1,870 feet per second, after 6,000 yards it is $2{,}500 \times (\cdot 75)^2$ or 1,400 feet per second, after 9,000 yards it is $2{,}500 \times (\cdot 75)^3$ or 1,060 feet per second. The rule does not apply when the velocity is reduced to or below that of sound (1,100 or 1,200 feet per second), since the law of resistance is then considerably modified.

Angle of descent.

Let V = velocity in feet per second.
R = range in yards.
θ = angle of descent.

When resistance is neglected

$$\text{Sin } 2\theta = \frac{3g\,R}{V^2} = \frac{100\,R}{V^2} \text{ roughly.}$$

Actually, the resistance causes V to vary; the above formula still roughly holds if V be taken as the sum of a quarter the initial velocity and three-quarters the final velocity.

The angle of elevation of gun is, for short ranges, very slightly less than that of descent; when final velocity is one-half initial velocity, this angle is from $\frac{2}{3}$ to $\frac{1}{2}$ that of descent.

(*The Engineer*, September 26, 1913.)

PARTICULARS OF 15 IN. 40-CALIBRE GUN.

	Weight in tons.
Two guns	165
Turret complete with armour . .	546
160 rounds of ammunition . . .	183
Total	894

Weight of steam pumping plant and hydraulic piping for 4 turrets (8 guns), 102 tons; weight of projectile, 1,950 lb.; weight of charge, 610 lb.; muzzle velocity, 2,300 feet/second.

(*Continued on p.* 388.)

BALLISTICS, WEIGHTS, ETC., OF

Sir W. G. Armstrong, Whitworth & Co., Ltd.,

		Semi-Automatic.			Semi-Auto		Naval Landing.
Diameter of Bore . in.	1·85	1·85	1·85	2·24	2·24	2·953	3
" " mm.	47	47	47	57	57	75	76
Length of Bore calibres	40	46	50	40	50	14·13	18·8
	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.
Weight of Gun . . .	4·51	5·0	7·5	7·5	10·5	1·875	4
" " kilos.	230	254	381	381	533	95	203
" Projectile lb.	3·3	3·3	3·3	6	6	11·75	12·5
" " kilos.	1·5	1·5	1·5	2·722	2·722	5·33	5·67
	oz.	oz.	lb. oz.	oz.	lb. oz.	oz.	oz.
" Charge M.D.Cordite	8·25	10	1 0	10	1 2·5	7·75	15
" " kilos.	0·234	0·283	0·453	0·283	0·525	0·22	0·369
Muzzle Velocity . F.S	2132	2300	2680	1968	2400	1100	1585
" " . M.S.	650	701	817	600	731	335	483
Muzzle Energy . . F.T.	104	121	164	161	240	98	213
" " . . M.T.	32·2	37·5	50·8	49·8	74·3	30·3	66
Penetration at Muzzle in. (Treaidder wrought-iron plate).	5·15	5·8	7·3	5·4	7·3	—	—
" " mm.	130·8	147·3	185·4	137·2	185·4	—	—
Rounds per Minute . .	25	25	25	25	25	20	20

Diameter of Bore . in	6	7·5	7·5	8	8	9·2	9·2
" " mm	152	190	190	203	203	234	234
Length of Bore calibres	50	45	50	45	50	45	50
	tons	tons	tons	tons	tons	tons	tons
Weight of Gun . . .	8·75	13·8	15·75	18·0	20·4	26·75	28·82
" " kilos.	8[illegible]90	14021	16[illegible]03	18289	20727	27179	29289
" Projectile lb.	100	200	200	250	250	380	380
" " kilos.	45·36	90·72	90·72	113·4	113·4	172·37	172·37
	lb.	lb.	lb.	lb.	lb.	lb.	lb.
" Charge M.D.Cordite	33·0	74	76	80	90	122	136
" " kilos.	15·0	33·566	34·473	36·29	40·82	55·34	61·7
Muzzle Velocity . F.S.	3000	29[illegible]0	3000	2846	3000	2750	3000
" " . M.S.	914	8[illegible]4	914	867	914	838	914
Muzzle Energy . . F.T.	6240	11[illegible]63	12481	14031	15600	19926	23714
" " . . M.T.	1932	3611·9	3865·2	4345·2	4831·2	6171	7340
Penetration at Muzzle in. (Treaidder wrought-iron plate)	25·5	30·6	32·3	32·2	34·9	35·2	40·1
" " mm.	647·7	777·2	820·4	817·9	886·4	894·1	1018·5
Rounds per Minute . .	9	6	6	5	5	4	4

Elswick B.L. and Q.F. Guns.

Elswick Works, Newcastle-on-Tyne.

		Semi-Auto.	Joint'd Gun.							
3	3	3	3	4	4	4·7	4·7	4·7	6	6
76	76	76	76	102	102	120	120	120	152	152
40	50	50	19·2	40	50	40	45	50	40	45
cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	cwt.	tons	tons
12	17·75	23	4·5	26	42	42	53	66	6·6	8·4
609	901	1168	229	1321	2134	2134	2692	3353	6706	8535
12·5	12·5	14·33	14·33	31	31	45	45	45	100	100
5·67	5·67	6·5	6·5	14·06	14·06	20·41	20·41	20·41	45·36	45·36
lb. oz.	lb. oz.	lb.	oz.	lb.	lb.	lb.	lb. oz.	lb.	lb.	lb.
2 0	3 0	5·75	15	5·5	10·5	6·125	9 11	14	24	31
0·907	1·36	2·608	0·425	2·495	4·76	2·78	4·395	6·35	10·886	14·061
2210	2600	3050	1485	2300	3000	2200	2600	3000	2500	2800
674	792	930	452	701	914	670	792	914	762	853
423	586	922	218	1137	1934	1510	2109	2808	4334	5436
131	181·5	285·5	67·5	352·1	599	467·6	653	869·6	1342·2	1683·4
8·0	10·3	13·7	—	11·6	17·4	12·1	15·6	19·3	19·4	22·9
203·2	261·6	348·0	—	294·6	442·0	307·3	396·2	490·2	492·8	581·6
20	20	30	15	12	12	12	12	12	9	9

10	10	10	12	12	12	12	13·5	14	16
254	254	254	305	305	305	305	343	355·6	406·4
40	45	50	40	40	45	50	45	45	40
tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
31	36·25	38·25	48·5	51	59·3	66·7	76	85	105
31497	36832	38864	49278	51818	60252	67770	77216	86360	106680
450	500	500	850	850	850	850	1250	1400	2200
204·12	226·8	226·8	385·55	385·55	385·55	385·55	567	635	998
lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
86·5	167	200	155	260	260	285	296	324	390
89·24	75·75	90·72	70·31	117·93	117·93	129·3	134·26	147	177
2400	2800	3000	2400	2650	2800	3000	2700	2700	2340
731	853	914	731	808	853	914	823	823	713
17973	27181	31203	38049	41386	46208	53046	63187	70770	83580
5566	8418	9663	10513	12816	14310	16428	19568	21916	25868
29·9	39·7	44·1	67·5	43·6	47·8	52·5	51·3	58·2	50·4
759·4	1008·4	1120·1	952·5	1107·4	1201·4	1333·5	1308·0	1351·3	1280
3	3	3	2	2	2	2	2	2	2

BALLISTICS, WEIGHTS, ETC., OF ELSWICK HOWITZERS AND FIELD GUNS.

Sir W. G. Armstrong, Whitworth & Co., Ltd., Elswick Works, Newcastle-on-Tyne.

	Mountain Gun.	Field.	Horse and Field.	Field.	Howitzers.			Field Position.	Howitzers.							
Diameter of Bore . in.	2·953	3	3	3·3	4	4·3	4·7	5	5	6	8	9·2	11	11·24	12	
,, ,, mm.	75	76	76	84	102	109·2	120	127	127	152	203	234	279·4	285·5	305	
Length of Bore calibres	15·2	28	23	28	8·75	12·5	12	32	8·4	12·2	12	13·7	12	15	17	
Weight of Gun . . .	lb. 260	cwt. 7·25	cwt. 6	cwt. 9	lb. 220	cwt. 7	cwt. 8	tons 2	cwt. 9	ton 1	tons 2·6	tons 4·3	tons 5·5	tons 7·85	tons 12·55	
,, ,, kilos.	118	368	305	457	100	356	406	2032	457	1016	2642	4369	5588	7976	12751	
,, Projectile lb.	12·5	14·3	12·5	18·5	20	40	35	60	50	100	240	290	500	661·38	981	771
,, ,, kilos.	5·67	6·49	5·67	8·39	9·07	18·14	15·87	27·22	22·68	45·36	108·9	131·5	227	300	445	350
,, Charge M.D.Cordite	oz. 10	oz. 20½	lb. oz. 1 4	lb. oz. 1 6	oz. 8½	oz. 16¼	lb. oz. 1 4½	lb. oz. 9 8	oz. 12	lb. oz. 3 0	lb. 7·5	lb. 14	lb. 20	lb. 32	lb. 53	lb. 56·25
,, ,, kilos.	0·283	0·582	0·567	0·624	0·241	0·461	0·582	4·31	0·34	1·361	3·4	6·35	9·07	14·51	24	25·51
Muzzle Velocity . F.S.	1250	1755	1700	1635	950	980	1150	2150	782	1000	1000	1250	1220	1230	1350	1585
,, ,, . M.S.	381	535	518	498	290	298	350	655	238	305	305	381	372	375	411·5	483

Vickers Howitzers and Field Guns.

		3 in. Mountain Gun.	3 in. Landing Gun.	3 in. Field.		Howitzers.					
				Light.	Heavy.	4·33 in.	4·7 in.	6 in.	8 in.	9·2 in.	11 in.
Diameter of Bore .	in.	3	3	3	2·95	4·33	4·724	6	8	9·2	11
Length of Bore . .	in.	42·94	66	64·69	99·46	58·45	66·15	94·5	128·8	128·8	154
Length of Gun . .	in.	47·23	70·34	69·3	103·8	63·55	71·05	102·8	138·2	141·2	168·25
Weight of Projectile	lb.	12·5	12·5	12·5	14·33	35·25	45	90·3	216·7	290	758
Weight of Gun . .	cwt.	2·45	3·9	4·5	7·5	725	9·75	18·75	46·75	tons ·3	tons 5·85
Muzzle Velocity . .	F.S.	1150	1640	1600	1660	1100	1000	1285	1100	1300	1000
Muzzle Energy . .	F.T.	115	233	220	274	296	312	1035	1820	3400	5260
Weight of Mounting complete with Shield . .		c. q. lb. 7 1 0	c. q. lb. 9 2 0	t. c. q. lb. 0 11 3 0	t. c. q. lb. 0 14 0 0	t. c. q. lb. 0 17 0 0	t. c. q. lb. 0 17 2 0	t. c. q. lb. 2 14 3 0	t. c. q. lb. 3 11 0 0	t. c. q. lb. 5 9 0 0	t. c. q. lb.
Thickness of Shield . .		·125	·192	·125	·144	None	·157	·236	·236	None	
Weight of Shield . . .		c. q. lb. 0 2 17	c. q. lb. 1 1 15	c. q. lb. 0 3 10	c. q. lb. 1 0 15	None	c. q. lb. 1 2 8	c. q. lb. 3 3 0	c. q. lb. 3 0 0	c. q. lb. None	
Angle of Elevation . .		25°	23°	16°	16°	50°	43°	50°	40°	55°	
Angle of Depression . .		15°	10°	6°	10°	5°	5°	None	None	3°	

VICKERS GUNS

Naval Guns. (This table is

	37 m/m. 30 cal.	37 m/m. 42·5 cal.	3-pdr. 50 cal.	6-pdr. 50 cal.	3 in. Semi-Auto. 50 cal.
Diameter of Bore . in.	1·457	1·457	1·85	2·244	3
Length of Bore . . in.	43·5	62	92·5	112·2	150
Length of Gun . . in.	73·75	94	98·9	118·6	156·995
Weight of Projectile lb.	1	1·25	3·3	6	12·5
Weight of Gun	cwt 3·75	cwt. 5·42	cwt. 5·53	cwt. 9·29	cwt. 19
Muzzle Velocity . . F.S.	1800	2300	2800	2600	2700
Muzzle Energy . . F.T.	22·5	45·85	179·4	281	632
Penetration of Wrought Iron Plate at Muzzle. Gavre formula . . in.	1·9	3·3	6·7	7·5	9·65
Penetration of Hard Steel Plate at 3,000 yards. Gavre formula . . in.	—	—	—	—	—
Rounds per minute . .	300	300	30	28	25
Weight of Mounting complete with Shield . .	c. q. lb. 4 1 10	c. q. lb. 4 3 20	c. q. lb. 11 2 0	c. q. lb. 18 1 0	t. c. q. lb. 1 1 1 0
Thickness of Shield . .	·1875	·16	in. ·25	in. ·25	in. ·25
Weight of Shield . . .	c. q. lb. 0 3 11	c. q. lb. 0 1 22	c. q. lb. 1 0 0	c. q. lb. 1 2 8	c. q. lb. 2 1 0
Angle of Elevation . .	16°	15°	20°	20°	20°
Angle of Depression . .	25°	20°	20°	10°	10°

	7·5 in. 50 cal.	8 in. 50 cal.	9·2 in. 45 cal.	9·2 in. 50 cal.	10 in. 45 cal.
Diameter of Bore . in.	7·5	8	9·2	9·2	10
Length of Bore . . in.	375	388·75	429·3	460	450
Length of Gun . . in.	386·7	400	442·35	473	464·6
Weight of Projectile lb.	200	216·7	380	380	478·4
Weight of Gun	tons 16·0	tons 14·6	tons 26·85	tons 27·81	tons 34·85
Muzzle Velocity . . F.S.	3003	3090	2800	2950	2850
Muzzle Energy . . F.T.	12505	14350	20660	22930	26945
Penetration of Wrought Iron Plate at Muzzle. Gavre formula . . in.	30·75	31·5	35·3	38·0	38·9
Penetration of Hard Steel Plate at 3,000 yards. Gavre formula . . in.	11·4	12·6	14·1	15·2	15·8
Rounds per minute . .	8	6	4	4	3
Weight of Mounting complete with Shield . .	t. c. q. lb. Depending on type of Mounting.				
Thickness of Shield . .					
Weight of Shield . . .					
Angle of Elevation . .					
Angle of Depression . .					

AND MOUNTINGS.
supplied by the Manufacturers.)

4 in. Semi-Auto.	4 in.	4·7 in.	4·7 in.	4·7 Naval Howitzer	6 in.	6 in.	7·5 in.
40 cal.	50 cal.	45 cal.	50 cal.	18 cal.	45 cal.	50 cal.	45 cal.
4	4	4·724	4·724	4·724	6	6	7·5
160	201·15	212·6	228·45	85	269·5	300	337·5
166·6	208·45	220	236·2	89·9	279·2	310·07	349·2
31	31	45	45·14	45	100	100	200
cwt.	cwt.	tons	tons	c. q. lb.	tons	tons	tons
25	41	3·18	3·2	11 1 14	7·42	7·8	14·02
2300	3030	2800	3050	1200	2900	3100	2875
1137	1975	2445	2910	450	5830	6665	11465
10·8	16	15·9	17·8	—	22·6	24·8	28·75
—	—	—	5·0	—	7·8	8·8	10·6
20	15	12	12	10	10	10	8
t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.
1 10 2 0	2 6 3 0	3 13 3 0	6 5 3 0	4 8 1 11	9 1 1 0	12 0 2 0	Depending on type of Mounting.
in.		in.	in.	in.	in.	in.	
·028	none	2 and ·313	4·33	2	3	3 and 1·5	
c. q. lb.		c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	
1 1 0	none	117 0 0	2 8 2 0	1 9 1 14	3 1 1 0	5 5 0 0	
		1 1 0					
20°	15°	20°	16°	70°	15°	15°	
10°	10°	7°	7°	5°	7°	7°	

10 in.	12 in.	12 in.	13·5 in.	14 in.		15 in.	
50 cal.	45 cal.	50 cal.	45 cal.	45 cal.		45 cal.	
10	12	12	13·5	14		15	
486	540	600	607·5	630		675	
500	557·55	617·7	625·9	648·4		695·3	
496·4	850	850	1250	1400	1488·12	1720	1950
tons	tons	tons	tons	tons	tons	tons	tons
28·7	57·7	65·85	76·125	80·25	80·25	96	96
2863	2850	3010	2700	2615	2525	2655	2500
28225	47875	53400	63190	66385	65790	84070	84510
40·2	48·3	52·1	52·8	52·0	51·5	57·2	57·5
16·4	21·0	22·2	22·8	22·9	22·6	25·1	25·5
3	2	2	1·5	1·35	1·35	1·2	1·2

Coventry Ordnance

	3-pdr. 50 cal.	6-pdr. 50 cal.	Mountain 3·3 in. 20-pdr. Howitzer.
Diameter of Bore . . . . . in.	1·85	2·244	3·3
„ „ . . . . . mm.	47	57	83·8
Length of Gun . . . . . in.	99·0	119	45·25
„ „ . . . . . mm.	2514·5	3022·5	1149·2
Weight of Charge . . . . lb.	1·1	1·75	·5
„ „ . . . . kgs.	·5	·8	·23
Weight of Projectile . . . kgs.	1·5	2·72	9·07
„ „ . . . lb.	3·3	6·0	20·0
	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.
Weight of Gun	0 6 0 0	0 10 0 0	0 2 2 0
„ „ . . . . . . kgs.	304·8	508·0	127·0
Muzzle Velocity . . . . F.S.	2800	2800	860
„ „ . . . . . M.S.	853	853	262
Muzzle Energy . . . . . M.T.	55·6	101	31·6
„ „ . . . . . . F.T.	179·4	326	102
Penetration of Wrought Iron Plate at Muzzle. Gavre's formula . . in.	—	—	—
„ „ „ mm.	—	—	—
Penetration of Hard Steel Plate at 5,000 yards. Gavre's formula. . in.	—	—	—
„ „ „ mm.	—	—	—

	4 in. 50 cal.	4·7 in. 50 cal.	6 in. 50 cal.
Diameter of Bore . . . . . in.	4·0	4·7	6·0
„ „ . . . . . mm.	101·6	120·0	152·4
Length of Gun . . . . . in.	203	242·5	310
„ „ . . . . . mm.	5283	6159·2	7873·8
Weight of Charge . . . . lb.	11·25	16·0	31·0
„ „ . . . . kgs.	5·1	7·26	14·03
Weight of Projectile . . . kgs.	14·03	20·41	43·33
„ „ . . . lb.	31	45	100
	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.
Weight of Gun	2 2 0 0	3 14 2 0	8 15 0 0
„ „ . . . . . . kgs.	2134	3785	8890
Muzzle Velocity . . . . F.S.	3000	3000	2950
„ „ . . . . . M.S.	914	914	900
Muzzle Energy . . . . . M.T.	599	870	1869
„ „ . . . . . . F.T.	1934	2810	6034
Penetration of Wrought Iron Plate at Muzzle. Gavre's formula . . in.	16	17·4	23·1
„ „ „ mm.	406·4	441·9	586·7
Penetration of Hard Steel Plate at 5,000 yards. Gavre's formula. . in.	—	2·6	5·5
„ „ „ mm.	—	66	139·7

Works' Guns.

Field.				3 in.	3 in.	4 in.
12½-pdr. 23 cal.	15-pdr. 33·44 cal.	4·65 in. Howitzer.	6 in. Howitzer.	40 cal.	50 cal.	40 cal.
3·0	3·0	4·65	6·0	3·0	3·0	4·0
76·2	76·2	117·5	152·4	76·2	76·2	101·6
75·0	100·34	72	101·5	123·6	154·5	166·4
1904·9	2548·5	1828·8	2578	3139·3	3924	4226·4
1·0	1·626	1·1	5·0	2·0	5·25	5·25
·45	·74	·5	2·27	·91	2·38	2·38
5·67	6·8	17·01	45·36	5·67	5·67	14·06
12·5	15·0	37·5	100	12·5	12·5	31·0
t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb
0 6 0 8	0 8 2 0	0 8 2 0	1 2 2 0	0 12 1 0	0 18 2 21	1 5 3 1[illegible]
304·8	431·8	431·8	1143	622	948	1315
1600	1850	1000	1120	2300	3000	2300
488	564	305	341	701	914	701
68·7	110	80·5	269	142	242	352
222	356	260	870	258·5	780	1137
—	—	—	—	7·7	11·25	10·8
—	—	—	—	195·5	285·7	274·3
—	—	—	—	—	—	—
—	—	—	—	—	—	—

7·5 in. 50 cal.	9·2 in. 50 cal.	11·02 in. 50 cal.	12 in. 50 cal.	13·5 in. 45 cal.	14 in. 45 cal.	14 in. 45 cal.
7·5	9·2	11·02	12·0	13·5	14·0	14·0
190·5	233·7	280	304·8	342·9	355·6	355·6
387·5	475	568	617·7	630	648·7	648·7
9842·2	12064	14427	15689	16001	16476	16476
71·0	95	270	285	290	300	305
32·2	43·09	122·47	129·28	131·54	136·08	138·35
90·72	172·36	344·72	385·56	567·0	635·0	726
200	380	760	850	1250	1400	1600
t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb.	t. c. q. lb	t. c. q. lb.
15 10 0 0	28 0 0 0	42 0 0 0	67 0 0 0	76 10 0 0	81 0 0 0	81 0 0 0
15749	28449	42674	68075	77728	82300	82300
2950	2950	2950	2950	2600	2600	2450
900	900	900	900	792	792	747
3737	7101	14203	15884	18148	20322	20619
12068	22930	45861	51290	58530	65620	66580
29·8	37·9	51·2	50·65	49·1	51·2	51·7
756·9	962·6	1300·3	1286·4	1247	1300·3	1313·2
8·5	12·3	18·0	18·3	18·3	19·3	20·7
215·9	312·4	457·2	464·8	464·8	490·2	525·8

(*Continued from p.* 379.)

Range in yards.	Elevation of Gun.	Remaining Velocity in feet per second.	Penetration in inches into Modern Armour Plate.
3,280	1° 53′	2,090	18·0
6,560	3° 59′	1,890	15·5
9,840	6° 24′	1,700	13·1
13,100	9° 19′	1,530	11·3
16,400	12° 41′	1,420	10
19,700	16° 36′	1,330	9·1

Note.—The penetrations are obtained by formula; those given for armour of greater thickness than 12 inches are probably under-estimated.

Armour Bolts.

For 4″ to 7″ armour use $3\frac{1}{4}$″ bolts; for 8″ to 12″ use $3\frac{3}{4}$″ bolts.
Minimum distance of centre of bolt from edge of plate, 12″.
Arrange one bolt to each 7 or 8 square feet of plate.
For weight of bolts add $1\frac{1}{8}$ (thick plates) to $1\frac{1}{2}$ (thin plates) per cent to the weight of the armour taken as unperforated.

NOTES ON MACHINERY.

Rating of Motor-boats.

$$\text{Rating} = 60\sqrt{\frac{\text{P}}{\text{S}} + \sqrt{\frac{\text{L}}{\text{B}}}} + 2\text{S}.$$

S = area of greatest immersed section in square feet.
L = length in feet at a distance 4 inches above L.W.L.
B = beam on L.W.L. to outside of planking at the position of the greatest immersed section.
P = 'motor-power.'
= $7 \times \sqrt{\text{A}} \times \text{N}$ for 4-stroke motors.
= $10 \times \sqrt{\text{A}} \times \text{N}$ for 2-stroke motors.
A = area of exhaust orifice in square inches.
N = number of cylinders.

Rating of Motor-engines.

(*Royal Automobile Club.*)

H.P. = number of cylinders × square of diameter in inches ÷ 2·5.

Note.—This formula assumes a piston speed of 1,000 feet per minute.

NOTES ON MACHINERY.—SIZES OF MACHINERY SPACES.

Class of Ship.	H.P.	Number of Shafts.	Engine-room.			Boiler-rooms.		
			Length.	Breadth.	Height.	No.	Length (each).	Breadth (each).
			ft.	ft.	ft.		ft.	ft.
Battleship (turbine) . . .	30,000	4	70	62	26	3	37	50
,, ,, . . .	25,000	4	68	57	25	2	38	47
,, (reciprocating) .	18,000	2	54	48	26	3	{ 36 (2) 20 }	53
Cruiser ,, . . .	27,000	2	68	38	26	4	35	43
Light cruiser ,, . . .	8,000	2	48	34	22	2	40	34
,, (turbine) . . .	10,000	2	47	38	12	3	{ 40 (2) 20 (1) }	26
T.B. destroyer ,, . . .	16,000	3	44	24	17	2	{ 39 23 }	24
Liner ,, . . .	70,000	4	152	75	37	4	80	50
Fast Channel steamer (do.)	14 000	2	38	35	15	2	36	32
Liner (combined)	9,000	3	56	68	36	2	37	50
Passenger steamer (do.) . .	8,000	4	35	50	23	1	43	52
Cargo steamer (reciprocating)	3,300	1	27	14	25	1	34	32 to 16
,, ,,	1,750	1	45	54	30	combined space		
Sea-going tug ,,	1,500	1	26	32	28	1	38	19

WEIGHTS OF MARINE ENGINES AND BOILERS.

(*Compiled by Percy A. Hillhouse, B.Sc., M.I.N.A., and reprinted by permission from Kempe's "Engineer's Year Book" *.*)

Type of Ship.	Type of Engine.	Type of Boiler.	Horse-power per ton total.	Weight of Engines Tons per H.P.	Weight of Boilers. Tons per H.P.
Cargo Steamers	Reciprocating	Cylindrical	4·57	·107	·112
	Geared Turbines	,,	4·50	·105	·117
Mail Steamers	Reciprocating	,,	5·56	·085	·095
	Direct Turbines	,,	9·72	·037	·066
	Geared ,,	,,	8·00	·050	·075
	,, ,,	Oil-fired water-tube	9·35	·050	·057
Channel Steamers	Direct Turbines	Cylindrical	13·00	·022	·055
	,, ,,	Water-tube	15·00	·022	·045
	Geared Turbines	Cylindrical	11·50	·033	·054
	,, ,,	Water-tube	13·50	·033	·041

* Published by Crosby Lockwood & Son.

WEIGHT OF WARSHIP'S MACHINERY.

In large turbine-driven ships take 16 to 20 H.P. per ton; in destroyers up to about 60. About one-half the weight is in the engine room.

POUNDS OF COAL PER H.P. PER HOUR.

For all purposes at maximum power.

Average values.—Battleships 1·7 T, 2·2 R; cruisers 1·6 T, 2·2 R; destroyers 1·6 T; high-speed passenger vessels, 1·5 T, 1·6 R; cargo vessels 1·75 T, 1·8 R; steamboats 2½ to 3, exceptionally as low as 1·3 is obtained. (T = turbine, R = reciprocating.)

For oil fuel take ·7 the weight of coal.

For wood fuel take 8 if damp, 6 if dry.

For internal combustion engines (petrol or paraffin) take ·8 lb. per B.H.P. per hour.

Number of tons of coal per 24 hours = ·0107 × H.P. × number of lb. per H.P. per hour.

NOTES ON DESIGN.

DETERMINATION OF DIMENSIONS.

As a first approximation the dimensions are determined from those of a fairly similar ship, using the same block coefficient of fineness.

The *length* is then examined from the point of view of (*a*) the sum of the lengths of the necessary compartments and (*b*) the minimum length for economical propulsion. In slow ships (*b*) is of little importance ; the necessary lengths of machinery spaces, holds, and (in warships) of magazines, which form the midship portion of the ship, together with the same lengths of bow and stern as have been previously adopted give on addition the total length of ship. In vessels of high or even moderate speed, the length for economical propulsion is determined by experience with the help of the table on p. 171.

Subject to these requirements the length is kept as small as practicable, for any increase of length leads to additional hull weight and cost ; in armoured ships the relative armour weight also rapidly increases with the length, while manœuvring power diminishes. It may therefore be advisable to accept a length smaller than that desirable from propulsive considerations.

The product of the *beam* and *draught* is known when displacement, length, and coefficients of fineness are determined. The draught is frequently limited by the service for which the vessel is intended ; in that case the beam is then at once found. Usually the ratio of beam to draught is determined from considerations of stability.

When trial dimensions have been decided on, the design can be roughly worked out, and the weights of the various components approximated to. A rough approximation to the power gives the weight of machinery when the H.P. per ton (p. 390) is known. Generally it is found that some small alterations are then required in the dimensions. The effects of these or of changes in the design conditions are dealt with below.

CHANGE OF STABILITY.

If the metacentric height is found to be too great or insufficient, it is readily adjusted by the process described on p. 129. If the beam and draught are both free, the length need not be altered ; if the draught is fixed, either the length must be changed to suit the change necessitated in the beam or the shape of the midship section altered. The displacement is assumed to remain constant. Alternatively, by changing the form of L.W.L. aft, it is possible to modify the position of the metacentre without changing the principal dimensions. If this is admissible, it can be left to a later stage. (See "Preparation of Lines".)

Change of Dimensions due to Addition of Weight.

This may be necessitated by the total weight being found to be in excess or defect of the assumed displacement. It is assumed that all dimensions increase in proportion.

The total weight W is divisible into certain items (p. 102); these are grouped into two parts, the first of which includes items whose weight varies as the displacement, and the second items whose weight is constant. Hull would be included in the first part, and load (passengers, cargo, or armament), equipment, and usually coal would be included in the second part. Machinery might all be included in the first part, or its weight might be assumed to vary as $W^{\frac{2}{3}}$; armour varies partly (main belt) as $W^{\frac{1}{3}}$, partly (decks) as $W^{\frac{2}{3}}$, and is partly constant. One-third of all weight varying as $W^{\frac{1}{3}}$ and two-thirds of all weights proportional to $W^{\frac{2}{3}}$ should be included in the first part ; the remainder should be put in the second.

Call the first part KW, and the second P, $W = KW + P$; or $W = P/(1-K)$.

If P is increased by p, W must therefore increase by $p/(1-K)$. Generally each ton added to the constant term or load necessitates an addition to the displacement of 2 to 4 tons, taking the higher number in vessels of high speed.

Alteration of Speed.

K = coefficient as above (including machinery weight) = ·6 for many ships of moderate speed.

n = index of speed at which power varies, say 4·5 for most ships, to 3 for very fast or very slow ships.

λ = number of H.P. per ton of weight of machinery and boilers (p. 390).

I = original H.P.

W = original displacement in tons.

V = original speed.

v = increase of speed (supposed moderate).

$$\text{Increase of H.P.} = nv \Big/ V\left\{\frac{1}{I} - \frac{7-n}{6[I + W\lambda(1-K)]}\right\}$$

$$\text{Increase of displacement} = n\frac{v}{V}w \Big/ \left(1 - K + \frac{(n-1)w}{6W}\right)$$

where w is the original machinery weight $(= I/\lambda)$.

Example.—A ship of 20,000 tons displacement has a speed of 21 knots, H.P. 25,000 ; 60% of the weight varies as the displacement, the remaining 40% being constant. The machinery weight is 2,200 tons. Find the displacement and H.P. required (*a*) if additional weight aggregating 1,200 tons must be added, (*b*) if no weight is added, but the speed is increased by 1 knot.

(*a*) $\kappa = \cdot 6,\ p = 1200$.

$$\text{Increase of displacement} = \frac{1200}{1 - \cdot 6} = \frac{1 \cdot 200}{\cdot 4} = 3{,}000.$$

New displacement = 23,000 tons.

$$\text{New I.H.P.} = 25{,}000 \times \left(\frac{23}{20}\right)^{\frac{2}{3}}$$
$$= 25{,}000\left(1 + \tfrac{2}{3} \times \tfrac{3}{20}\right) \text{ approximately,}$$
$$= 27{,}500.$$

(*b*) $n = 4 \cdot 5;\ v = 1;\ \lambda = 25{,}000/2{,}200 = 11 \cdot 4$.

By first formula, increase of H.P. = $4 \cdot 5 \div$

$$21\left\{\frac{1}{25{,}000} - \frac{2 \cdot 5}{6[25{,}000 + \cdot 4 \times 11 \cdot 4 \times 20{,}000]}\right\} = \text{about } 6{,}000.$$

By second formula, increase of displacement =

$$\frac{4 \cdot 5}{21} \times 2{,}200 \div \left(\cdot 4 + \frac{3 \cdot 5 \times 2{,}200}{6 \times 20{,}000}\right) = 1{,}000 \text{ tons.}$$

So that the new H.P. is 31,000, and the new displacement 21,000 tons.

Preparation of Lines.

It is sufficient to take sections spaced L/10 apart (L = length b.p.), together with two additional sections situated L/20 from either end. The principal dimensions are supposed to be now fixed.

First determine and draw the curve of sectional areas (p. 91) and the load water-line. This is best accomplished by taking ordinates from a successful design of fairly similar proportions and corresponding speed, and modifying them in constant ratios that will ensure the displacement and beam desired. Find the longitudinal position of the centre of buoyancy from the area curve.

Then roughly estimate the longitudinal position of C.G. of the ship (its vertical position and the total weight should have been previously calculated in order to fix the dimensions). If this agrees with the position of C.B. as found above, no alteration is necessary; but in general the C.G. and C.B. will not be in the same vertical plane. This can be remedied in two ways:—

(1) Shift C.B. by altering the curve of areas. This should be done preferably in the after body (see p. 176). It is advisable not to attempt too large a shift forward as the propulsion may be seriously affected, particularly at moderate or fairly high speeds, but usually a reasonable shift aft can be made without loss. At slow or very high speeds more latitude can be given, provided that fairness is maintained. A convenient way of effecting this shift is to move the midship or largest section, say, aft through a distance d equal to $h/(1 - 2l/L)$ or about 2·5 h, where h is the shift

aft of C.B. desired, and l the distance between the C.G.s of the forward and after portions of the curve of areas. The perpendiculars remain where they were; but the fore body is uniformly stretched and the after body contracted, the shift of any section originally distant x from ⅔ being $2hx/L$.

(2) Shift C.G. by altering weights. Usually the machinery (and in warships the whole citadel) can be moved forward or aft as may be necessary to get the C.G. in its correct position. This method is often preferable to (1), particularly when C.G. is found to be before C.B., since the propulsion is not involved.

Modify the L.W.L. aft if necessary to adjust the stability (p. 391). This should be done cautiously, though more latitude is allowable here than in alterations to the curve of areas.

Sketch a body, using a planimeter to ensure that the sections have the areas determined. Roughly fair with a bilge diagonal.

Check the "critical sections", viz., through propellers to ensure adequate clearance 12 in. to 15 in., and through ends of engine-room, and fore end of boiler-room to ensure there being sufficient space; also in warships through the end barbettes and magazines. Find where the shafts leave the ship; the unsupported outboard lengths should not be excessive. The propellers should clear, when possible, in transverse view; and care should be taken that the lines permit a ready flow of water to them from forward. The position and extent of the side docking keels (if any) require consideration.

The stem and stern can then be drawn in, and the sections carried above the L.W.L. to the upper and forecastle decks. A midship section can be prepared showing the construction and scantlings. Where necessary the longitudinal strength can be investigated (taking a coefficient for the bending moment from a previous similar ship), and the scantlings revised if necessary. When finally decided upon, a second approximation to the weight and vertical C.G. can be made (all items but hull and machinery are definitely known); if this confirms the previous estimate, the design can be proceeded with.

The final complete calculations for the design usually occupy considerable time, and are not finished until the design is nearly completed. If the previous approximate calculations have been properly carried out, and the effect of all important alterations introduced when working out the design have been carefully considered, it is improbable that any further modifications in the dimensions or lines will be necessary.

FANS FOR SHIP VENTILATION.

PARTICULARS OF SHIP VENTILATING 'SIROCCO' (Trade Mark) FANS.

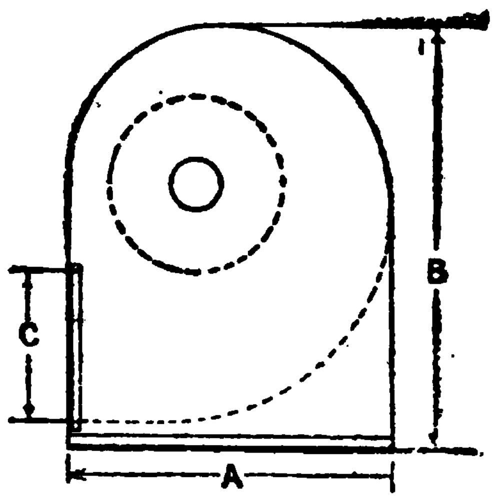
Manufactured by Messrs. Davidson & Co., Ltd., Sirocco Engineering Works, Belfast.

		'High-pressure' fans.								
Nominal size of fan in inches	7½	12½	17½	20	25	30	35	40	45	50
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Dimension A (fig. 232, p. 396)	1 5 1/16	2 3	2 9 7/8	3 1 13/16	3 10 3/8	4 6 5/8	5 8¼	5 11¾	6 8¾	7 5¼
" B	1 6 3/16	2 4¼	2 11 3/8	3 8 3/8	4 11¼	5 10¾	6 10	7 8 1/8	8 7	9 6 1/8
" C	7	8	10	1 4	1 8	2 0	2 4	2 8	3 0	3 4
Width of casing excluding inlet	7	8	10	1 4	1 8	2 0	2 4	2 8	3 0	3 4
Width of coned suction	2½	3	4	5	6¼	7½	8¾	10	11¼	1 0¼
Diameter of eye	8	1 4	1 8	1 11	2 4¾	2 9¾	3 8¼	3 8¾	4 1¾	4 7¼
Weight of casing (cwt.)	·40	·88	1·88	2·62	4·79	5·88	7·88	12·23	18·25	24·36
Weight of runner (cwt.)	·13	·40	·71	·75	1·08	1·75	2·38	3·42	4·68	5·93
Output of air with free inlet, in cubic feet per minute, against discharge pressures of water gauge 3½"	—	1200	2400	—	—	—	—	—	—	—
3"	—	1600	3200	—	—	—	—	—	—	—
2"	500 at 1½"	2000	4000	4000	6000	9000	12000	16000	20000	25000
1"	900	2200	4200	7500	12000	17500	23500	31500	40000	50000
Revolutions per minute at 1" w.g. discharge pressure	1350	950	750	700	575	475	400	350	310	285
Size of square testing inlet and outlet trunks, in inches	10 (outlet only)	10	14	—	—	—	—	—	—	—
Size of trunking (square) suitable for fan in inches	7	13	18½	24	30	36	42	48	54	60
B.H.P. of motor	·25	1·5	3·3	4·0	6·6	8·9	13·1	16·7	21	26
Total weight of fan and motor in cwt.	1·62	6·5	9·2	11·4	15·8	21·6	28·5	33·5	42	52

Fans for Ship Ventilation.

(See table on p. 395.)

Fig. 282.



Notes.—The outputs by air in the above table are slightly lower, and the horse-powers higher, than those obtained by test, thus providing a margin against slight reductions of efficiency. The B.H.P. of motor is that corresponding to free inlet and outlet; at increased pressures the actual B.H.P. may be only ⅔ of this.

The discharge pressures given are the 'side' pressures, i.e. those measured from a water-gauge flush with the side of the trunk.

The trunks for 20″ and large fans are in all cases sufficiently large to reduce the difference between 'side' and 'head on' pressure to a negligible amount. For 12½″ and 17½″ fans the total heads, or 'head on' pressures are, for side pressures of 1″, 2″, 3″, 3½″ water-gauge, 1·62″, 2·52″, 3·33″, and 3·69″ respectively. For a 7½″ fan, 1″ side pressure corresponds to 1·1″ total head.

The sizes of suitable trunking are calculated on a basis of velocity of 1,500 feet per minute, with outputs at about 1½″ *w.g.* for all the larger fans and at about 2½″ *w.g.* for the 12½″ and 17½″ fans. When the latter fans are used against high resistances—such as air coolers or heaters—the trunks, if short, may be 10″ and 14″ square respectively; trunking of unusual length or containing many bends or abrupt changes of section should be increased in size.

General Notes on Ventilation and Movement of Air.

Air weighs at standard barometric pressures and temperatures and with 70% humidity 0·08 lb. per cubic foot, which is equivalent to 13 cubic feet per lb.

If p = weight in lb. per cubic feet, at 70% humidity ;
b = height of mercury barometer in inches ;
T = temperature in degrees Fahrenheit ;
g = acceleration due to gravity = 32·2 ;

then $\sqrt{\frac{2g}{\rho}} = 42 \cdot 25 - 0 \cdot 5b + 0 \cdot 03\text{T}$ approximately for moderate changes of pressure and temperature.

For air moving in ventilating systems, where changes of height, temperature, and pressure are small, the total head is equal to the sum of the pressure and velocity heads. Expressed, as usual, in inches water-gauge, it is the pressure registered by a gauge which faces directly the current of air.

Pressure head is that due to 'side' pressure, or that registered by a gauge connected to a hole in the side of the trunk.

Velocity head is that due to the kinetic energy of the air. The velocity corresponding to 1 inch water-gauge is, in feet per second, equal to $\sqrt{62{\cdot}5/12} \times \sqrt{2g/\rho}$. In feet per minute this becomes $5{,}790 + 4{\cdot}1\text{T} - 68{\cdot}5b$ approximately ; with a 30″ barometer and a temperature of 65° F., this velocity is 4,000 feet per minute. With any other velocity v feet per minute, the velocity head is equal to $\left(\frac{v}{4000}\right)^2$ inches w.g.

For air moving along a tube without resistance, the total head (i.e. side pressure + velocity head) is constant. The side pressure therefore increases where the velocity head decreases, i.e. where the tube is enlarged ; and vice versa. On emerging into the atmosphere the side pressure is zero ; it may thence be determined at any other point, being equal to the difference in the velocity heads. (This is irrespective of any change of volume due to the changing conditions.)

In actual trunking various kinds of resistance are experienced, each of which is equal to the velocity head multiplied by a coefficient F.

(*a*) *Frictional resistance.*—In average trunking, square or circular, F = 1 for a length of trunk equal to 40 times the diameter or side. For shorter or longer lengths take F proportional. For rectangular trunks of sides a and b take an equivalent side equal to $\frac{2ab}{a+b}$.

(*b*) *Resistance due to bends.*—For a right-angled bend F = 1·5. For bends of inner radius equal to the depth of trunk in the plane of bend the resistance is fairly small. After all bends the flow of air is concentrated on the outer side of the bend.

(*c*) *Resistance due to changes of section.*—For a contraction the sides may be sloped 1 in 2 without appreciable loss. For an enlargement loss occurs if each side is sloped more than about 1 in 12. In the worst case, when the enlargement is sudden, F (referred to the smaller velocity) is $1 - \frac{1}{n^2}$ where *n* is the area ratio.

(*d*) *Resistance due to obstructions.*—These vary according to nature and area of obstruction. For armour bars of ordinary spacing F = ·72. For a nest of closely spaced tubes in a cooling tank it may be as high as 6. For a suction trunk built closely round the eye of the fan and of depth equal to the side of discharge orifice, leading off perpendicular to eye axis F = 1·5. For a diaphragm constricting area to 70%, F = 1·2; to 40%, F = 8; to 20%, F = 60.

Adding these losses together we can express—

Final total head = Initial total head + head lost.

This equation enables the velocity of the air in any system of trunking to be calculated from the difference of pressure at the ends.

Power in Air Circuits.

Air horse-power is equal to the supply of air in cubic feet per minute multiplied by the total head in inches, w.g., and divided by 6,340. If measured at the fan delivery, it represents the effective horse-power of the fan. The electrical horse-power supplied to the motor is commonly 2 or 3 times the air horse-power. Multiply this by 746 for the number of watts.

Example.—A compartment requires 2,000 cubic feet of air per minute, which is supplied through trunks of aggregate length 60 feet, and 10 inches square in section. Bends, etc., in the circuit give a total value of 2·5 to F. Determine the pressure (total) and horse-power.

F due to friction is $\frac{60 \times 12}{40 \times 10} = 1{\cdot}8$. Total F = 2·5 + 1·8 = 4·3.

Pressure head = 0 at outlet.

Velocity head throughout $= \left(\frac{2000 \times 12}{10 \times 4000}\right)^2 = {\cdot}36$ inches w.g.

Head lost due to resistance = ·36 × 4·3.

Total pressure at fan = ·36 × 5·3 = 1·9″.

Air horse-power $= \frac{1 \cdot 9 \times 2000}{6340} = {\cdot}6$.

Electrical H.P. = ·6 × 2·5 (say) = 1·5; watts = 1·5 × 746 = 1,120.

Note.—In the above if a bell-mouth be added to the discharge trunk of size 12″ square, F is increased by ·2

(say), but the velocity head at outlet is now $(\frac{10}{12})^4$ = about $\frac{1}{2}$ its former amount. Total pressure at fan is ·36 (4·5 + ·5) = 1·8″ or about 5% less; and the output of air would be correspondingly increased.

Position of Trunks in Compartments.

Air entering a compartment will, unless the velocity be very small, travel a considerable distance across the compartment in almost a straight line in the direction in whch the trunk is pointed. On the other hand, air leaving a compartment travels radially from all directions to the exhaust orifice, its motion being independent of the direction of the trunk.

Supply trunks should therefore be pointed away from exhaust orifices to ensure a good circulation of air. They should, when supplying cold air, be directed horizontally just beneath the beams; the density of the cold air is sufficient to cause a good circulation on the floor. In very hot compartments, such as engine-rooms, they may be directed towards the spaces where men are generally working. When supplying heated air they should, on the other hand, point downwards; in such cases it may be necessary to have a shifting mouthpiece whose direction can be changed.

Exhaust trunks should have their orifices as high as possible.

The efficiency of the installation is improved if bell-mouths of sufficient size to reduce the air velocity to 1,200 feet per minute or less be fitted to both supply and exhaust openings. That on the exhaust can be short, sloping 1 in 2 on each side. That on the supply must taper gently—not more than 1 in 12 each side; and draughts are reduced if they can be made of sufficient length to reduce the velocity well below 1,200 feet per minute, since even 200 feet per minute is perceptible.

Quantity of Air required.

Boiler-rooms.—Allow under forced draught 18 lb. of air or 230 cubic feet per lb. of coal burnt; with oil fuel allow 20 lb. of air or 260 cubic feet per lb. of oil. Under natural draught multiply these amounts by $1\frac{1}{3}$.

Sleeping spaces.—Fifty cubic feet of air per man per minute is an ample allowance. In messing and similar spaces occupied intermittently by men, this allowance is unnecessary; about one-half is generally sufficient (see Board of Trade Regulations below).

Miscellaneous spaces.—These, if packed with men, may be dealt with as above; otherwise it is usual to allow so many minutes for complete renewal of the air in the compartment.

In U.S. Navy, this allowance is as follows :—

Space.	Number of minutes for complete renewal of air
Officers' quarters and crew space outside armour	10 to 12
Do. inside armour . . .	4 to 6
Sick-bay	8
w.c.'s	4
Store-rooms	10 to 15
Magazines	4 to 8
,, (for cooled air) . .	6 to 12
Engine-rooms	2
Steering gear compartments . .	8
Workshops	4
Dynamo-rooms	1
Switchboard-rooms . . .	6
Ice-machine rooms . . .	4

Efflux of Air through an Orifice.

p_1 = initial gauge pressure in inches of water.
p = actual gauge pressure in inches of water after time t (seconds).
V = volume of compartment in cubic feet.
A = area of orifice in square inches.
Q = rate of efflux in cubic feet per minute.
T = time in seconds required to reduce pressure from p_1 to atmospheric.

For moderate pressures p_1 and p—

$Q = 20A\sqrt{p}$ for a plain orifice.
$t = V(\sqrt{p_1} - \sqrt{p}) \div 70A$.
$T = V\sqrt{p_1} \div 70A$.

Note.—The time necessary to reduce pressure to half its amount is about one-third that for pressure to become atmospheric.

This formula could be used to detect the size of any opening causing leakage in a W.T. compartment by putting it under air pressure from a fan and noting with a water gauge the rate at which the pressure drops when the fan is cut off and the trunk closed.

Board of Trade Rules for Ventilation of Steerage Compartments and Hospitals in Emigrant Ships.

Natural ventilation.—Each compartment to have cowls, or equivalent, having an aggregate area of 5 square inches

per adult* accommodated. Area to be measured at narrowest part; half to be inlet and half outlet. In wings adjoining engine- and boiler-rooms this area to be increased by 33%.

Cowls to be carried to a convenient height above deck and to be clear of obstruction; area of cowl to be at least 50% more than that of pipe. When the pipes are bent or kneed, increase area as follows:—

(*a*) Curved bends (inner radius greater than diameter).—Angle of bend up to 30°, no addition; from 30° to 60° add 5% for each bend; from 60° to 90° add 10% for each bend.

(*b*) Curved knees (inner radius less than diameter).—As above, substituting 16% for 5%, and 36% for 10%.

Each cowl ventilator to project 3″ below roof of compartment, and downcasts are to be fitted with a canvas pipe extending to about 12″ above floor. Two cowls to be fitted in compartments containing up to 75 adults; three from 76 to 125 adults, and four for more than 125 adults.

Ventilators, or that portion leading to any one compartment, should not exceed 314 square inches in area (20″ diameter). The minimum diameter (except for hospitals and sanitary arrangements) is 10″.

A velocity of air of 800 feet per minute is assumed; the allowance to each adult is then 830 cubic feet per hour (13·8 cubic feet per minute). Trunkways built solely for ventilation and carried to sufficient height, may be accepted instead of cowls as either inlets or outlets, but not both; their area must be double that required for a cowl.

Hospitals should be ventilated independently and to the open air; the area required is 5 square inches of inlet, and the same for outlet per adult, with means for controlling the size of the openings. Sanitary arrangements should be ventilated to the open air.

In general no ventilator must pierce a transverse W.T. bulkhead.

Artificial ventilation.—The above rules hold for the general arrangements of trunks, and for the quantity of fresh air to be supplied (830 cubic feet per hour per adult + 33% in machinery wings; 1,660 cubic feet per hour per adult in hospitals).

General.—Inlets and outlets to be placed at opposite ends of compartments. The ventilation of each passenger deck is to be independent; that of the hold must not affect that of any of the passenger compartments.

* i.e. person of 12 years or more.

HYDRAULICS.

Duty of Ship's Pumps.

(*Engineer Commander J. E. Mortimer, M.I.Mech.E., M.I.N.A.*).

Type of Pump.	Bilge Centrifugal.	Three-throw Reciprocating Single-acting.		Portable Reciprocating Double-acting.
Capacity in tons per hour . . .	50	10	5	5
Diameter (inches) .	4	3½	2½	3½
Stroke (inches) . .	—	4	4	4¾
Including motor: Height .	3′ 3″	3′ 7″	3′ 7″	1′ 6″
Including motor: Floor space	5′ 0″ × 2′ 0″	2′ 4″ × 2′ 3″		1′ 8½″ × 3′ 9″
Including motor: Weight (cwt.)	13	9⅛	7⅝	8⅛
B.H.P. . . .	17	2	1¼	1¼
Delivery (gallons per minute) . .	187	37	19	19
Delivery pressure (lb. per square inch) .	60	30	30	13
Suction lift in feet .	25	25	25	20
Size of delivery pipe (inches) . .	4	2	2	1½

Table of the Pressure of Water at Different Heads.

H = head in feet. P = pressure in lb. per square foot. *p* = pressure in lb. per square inch.

H	P	*p*	H	P	*p*	H	P	*p*
1	62·4	·4333	5	312·0	2·1666	30	1872·0	13·0000
1·25	78·0	·5416	6	374·4	2·6000	40	2496·0	17·3333
1·5	93·6	·6500	7	436·8	3·0333	50	3120·0	21·6666
1·75	109·2	·7583	8	499·2	3·4666	60	3744·0	26·0000
2	124·8	·8666	9	561·6	3·9000	70	4368·0	30·3333
3	187·2	1·3000	10	624·0	4·3333	80	4992·0	34·6666
4	249·6	1·7333	20	1248·0	8·6666	90	5616·0	39·0000

Discharge of Water from Sluices and Orifices.

V = theoretical velocity due to head of water in feet per second.
H = head of water in feet.
A = area of aperture or outlet in square feet.

Q = quantity discharged in cubic feet per second.
G = quantity discharged in gallons per minute.
g = force of gravity = 32·2.
v = velocity of real discharge in feet per second.
k = coefficient for different diameters of sluices.

$$V = \sqrt{2gH} = 8\cdot025\sqrt{H}$$
$$H = \frac{V^2}{2g} = \cdot01553V^2$$
$$Q = Ak\sqrt{2gH} = 8\cdot025Ak\sqrt{H}$$
$$G = 375Q = 3010Ak\sqrt{H}$$
$$v = k\sqrt{2gH} = 8\cdot025k\sqrt{H}$$

Table of the Values of Coefficient k.

For Short Square Tubes.						For Short Cylindrical Tubes.					
$\frac{\text{Lgth.}}{\text{Dia.}}$	k	$\frac{\text{Lgth.}}{\text{Dia.}}$	k	$\frac{\text{Lgth.}}{\text{Dia.}}$	k	$\frac{\text{Lgth.}}{\text{Dia.}}$	k	$\frac{\text{Lgth.}}{\text{Dia.}}$	k	$\frac{\text{Lgth.}}{\text{Dia.}}$	k
0	·617	20	·69	50	·59	1	·62	13	·73	49	·60
2	·814	30	·65	60	·56	2	·82	25	·68	60	·56
10	·75	40	·62	100	·48	4	·77	37	·63	100	·48

Time required to Fill or Empty a Compartment.

Δ = volume of compartment in cubic feet.
A = area of pipe or aperture in square feet.
K = coefficient (see above).
h_1, h_2 = initial and final heads of water in feet.

Time in minutes = $15\Delta/A(\sqrt{h_1}+\sqrt{h_2})K$, if aperture is under water.

Note.—When filling a compartment, such as a magazine, by means of a pipe whose open end is part way down the side, calculate separately the volumes above and below the level of the open end. The above formula gives the time for the upper volume; that for the lower portion = $7\cdot5\ \Delta/AK\ \sqrt{h}$ where h is the head to end of pipe.

If the pipe is long, or if it contains bends, valves, etc., replace K by $1/(1+F)$, where F has the value given on p. 404.

Flow of Water through Pipes.

h = difference between heads of water at ends of pipe in feet.
d = diameter of pipe in inches.

l = length of pipe in feet.
f = coefficient of friction for pipe.
F = sum of all coefficients of resistance referred to diameter d.
Q = cubic feet of water passing per second.
G = number of gallons per minute.
v = velocity of water at diameter d in feet per second.
g = 32·2 feet per (second)^2.

$$h = \frac{v^2}{2g}(1 + fl/d + F).$$

$$v = 8\sqrt{h/(1 + fl/d + F)}.$$

$$Q = vd^2/183 = \frac{d^2}{23}\sqrt{\frac{h}{1+fl/d+F}}.$$

$$G = 2{\cdot}05\ vd^2 = 16.4d^2\sqrt{h/(1 + fl/d + F)}.$$

d.	f for new iron pipes.		f for old iron pipes.	
	$v = 1$	$v = 10$	$v = 1$	$v = 10$
3	·0024	·0021	·0051	·0041
6	·0023	·0019	·0045	·0034
12	·0021	·0016	·0036	·0028
18	·0019	·0014	·0029	·0023
24	·0018	·0012	·0025	·0020
36	·0014	·0011	·0020	·0017
48	·0012	·0010	·0019	·0015
60	·0011	·0009	·0018	·0014

For steel riveted pipes take $f = \frac{5}{8}$ value for new iron pipe.
For brass or lead pipes take $f = \cdot 8$ value for new pipe.

VALUES OF F.

Sudden enlargement (referred to small diameter), area ratio λ . . . . $F = 1 - \frac{1}{\lambda^2}$
Gradual enlargement, angle θ F as for sudden enlargement × sin θ
Diaphragm, hole $\frac{3}{4}$ pipe area . . . . F = ·76
,, hole $\frac{1}{2}$,, ... F = 3·9
,, hole ·3 ,, ... F = 18
,, hole ·2 ,, ... F = 49
Cock partly open . . . . . F as with diaphragm × 1·8
Elbow, angle 60° . . . . F = ·36
,, ,, 90° . . . . F = 1
,, ,, 120° . . . . F = 1·86
Bend, ,, 90°, inner radius = $\frac{1}{2}d$ . . . . F = ·14

Note.—If any portion of the pipe is of diameter D (different to d), multiply F for resistances in that portion by $(d/D)^4$.

HEAT.

Thermal Properties of Materials.

Material.	Melting-point in degrees Fahr.	Coefficient of conduction—B.T.U. per square foot per hour for 1 in. thickness.	Linear expansion per degree Fahr. × one million.	Specific heat.
Air (62°F. constant pressure)	—	—	680	·24
Aluminium	1,250	1,000	12·8	·212
Antimony	810	125	6·2	·051
Asbestos millboard	—	1·2	—	—
Bismuth	500	51	7·6	·030
Brass	1,700	670	10·6	·090
Bronze	1,690	—	10·4	·086
Copper	2,000	2,100	10·0	·097
Cordite (density 1·57)	—	—	—	·36
Cork	—	·48	—	—
Glass	—	—	4·6	·12 to ·18
Gold	2,200	—	8·0	·032
Gun-metal	1,850	—	10·4	·088
Ice	32	16	21	·504
Iron, cast	2,200	480	6·0	·112
Iron, wrought	2,950	580	6·4	·113
Lead	620	240	15·9	·031
Mercury	39	45	33·0	·033
Nickel	2,810	—	7·1	·109
Petroleum	—	—	185	·51
Platinum	3,080	—	5·0	·032
Silicate cotton	—	·56	—	—
Silver	1,850	3,200	11·2	·056
Steam (212° F., constant pressure)	—	—	780	·477
Steel	2,450	320	6·4	·118
Tallow	92	—	—	—
Tin	445	440	13·2	·056
Water	—	—	265	1·00
Wood (fir)	—	1·04	3·0* 19·0†	·16
Zinc	750	900	17·0	·094

*Along fibre. †Across fibre.

Notes on Heat.

1. One *British Thermal Unit* (B.T.U.) is the amount of heat required to raise the temperature of 1 lb. of water by 1°F.
2. One B.T.U. is equivalent to 778 foot-lb. of work.

3. The loss of heat per square foot from a heated body is proportional to the difference between its temperature and that of the surrounding air. This loss is divisible into two parts—loss by radiation and loss by convection.

4. The loss by radiation in B.T.U. per hour per square foot for 1° F. excess of temperature is ·03 for highly polished surfaces, ·05 for polished brass or tin, ·75 for oil paint, wood, or canvas, ·65 for dull metallic surfaces, and ·82 for dull black.

5. The loss by convection depends on the shape and position of the surface. In still air the loss in B.T.U. per hour per square foot for θ° F. excess of temperature is about $K\theta \,.\, (\theta/23)^{\cdot 233}$, where K is—

$\cdot 363 + 1\cdot 05/r$ for a sphere of radius r inches.

$\cdot 421 + \cdot 307/r$ for a horizontal cylinder of radius r inches.

$\cdot 204\left(\cdot 726+\frac{\cdot 216}{\sqrt{r}}\right)\left(2\cdot 43+\frac{1\cdot 584}{\sqrt{r}}\right)$ for a vertical cylinder, radius r inches, height h feet.

$\cdot 361 + \cdot 233/\sqrt{h}$ for a vertical plane surface of h feet.

6. By assuming an approximate value of θ for (5), the total loss per square feet per degree per hour due to radiation and convection can be estimated. Call it E.

7. Similarly the loss due to conduction for 1° difference and t inches thickness is found by dividing the coefficient of conduction in the table by t. Call this C.

8. Then the total loss of heat passing through a lagging material and including the loss at two surfaces is, for a total temperature difference of θ, equal to $\theta/\left(\frac{2}{E}+\frac{1}{C}\right)$ per square foot per hour. If there are air gaps and several materials find $\frac{2}{E}$ for each air gap and $\frac{1}{C}$ for each material; the sum makes the denominator of the above expression.

9. The temperatures (F. = Fahrenheit, C. = Centigrade, and R. = Réaumur) are connected by F. = 1·8 C. + 32 ; R. = ·8 C. ; F. = 2·25 R. + 32.

10. Absolute temperature = F. + 461 or C. + 273.

AERODYNAMICS.

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FORCES ON PLATES.

The resistance of air to a plate moving in a direction normal to its surface is given by $R = KAV^2$ where R is in pounds, A is in square feet, V is in miles per hour, and K is a coefficient.

The value of K as determined by various authorities is as given in the table below.

Experimenter.	Size of plate in inches.	Velocity of experiment, miles per hour.	Value of K.	Method of experiment.
Square plates.				
Stanton	1·77×1·77	19	·00287	Plate in a current of air.
Hagen	2×2	4	·003	Whirling machine, 8 ft. radius
Borda	3×3	—	·0039	" " 3½ "
Dines	4×4	21	·0035	" " 28 "
Finzi and Soldati . .	4×4	22	·0031	" " 15 "
Eiffel	4×4	20-33	·00265	Plate in a current of air.
Desdouits	4×4	44	·0053	" carried on a train.
Hagen	6×6	4	·0032	See above.
Cailletet and Colardeau	6×6	55	·0029	Plate falling under gravity.
Langley	6×6	40	·0030	Whirling machine, 30ft. radius
Eiffel	6×6	20-33	·0027	Plate in a current of air.
Cailletet and Colardeau	8½×8½	50-64	·0028	See above.
Eiffel	10×10	20-33	·0027	Plate in a current of air.
"	10×10	40-80	·00286	" falling under gravity.
Institute of Koutchino	12×12	2-14	·0035	" in a current of air.
Dines	12×12	40	·0029	See above.
Finzi and Soldati . .	12×12	22	·0033	" "
Thibault	13×13	5½	·0048	Whirling machine, 4½ft. radius
Eiffel	14×14	38-76	·0031	Falling plate.
Dines	16×16	21	·0035	See above.
W. Froude	18×18	8-10	·0039	Plate carried on truck of experimental tank.
Eiffel	20×20	38-76	·0030	Falling plate.
Marriote	21×21	2½	·0049	Whirling machine, 4½ft. radius
Eiffel	28×28	38-76	·0031	Falling plate.
Reichel	33×33	90-110	·0042	Whirling machine, 21ft. radius.
Le Dantzec	39⅓×39⅓	2½	·0034	Falling plate.
Eiffel	39⅓×39⅓	38-76	·0032	" "
Didion	39⅓×39⅓	15	·0032	" "
Von Lossl	39⅓×39⅓	2	·0042	Whirling machine, 3½ft. radius
Finzi and Soldati . .	39⅓×39⅓	22	·0042	" " 15 "
Reichel	39⅓×39⅓	70-90	·0042	" " 21 "
Stanton	60×60	0-25	·0032	Plate in a natural wind.
"	120×120	0-25	·00322	" " "
Paris	notknown	0-90	·0049	" " "
Rectangular plates.				
Nipher	36×48	20-50	·0025	Plate carried on a train.
Rateau	12×20	80	·0027	" in a current of air.
Eiffel	6×9	20-33	·0027	" " "
Canovetti	54×92	12	·0036	" sliding down a sloping wire.
Hutton	4×8	6-8	·0033	Whirling machine, 4½ft. radius
Kernot	4½×8	12-27	·0033	" "
St. Loup	4×8	85	·0029	" " 10 "
Eiffel	9¾×19½	40-80	·0031	Falling plate.
"	6×12	20-33	·0029	Plate in a current of air.
Beaufoy	6×12	3-14	·0045	Whirling machine, 9 ft. radius.
Langley	6×12	20	·0033	" " 30 "
Canovetti	39·4×78·8	14	·0037	See above.
Stanton	60×120	0-25	·0032	Plate in a natural wind.
"	1×8	14	·0029	" in a current of air.

Experimenter.	Size of plate in inches.	Velocity of experiment, miles per hour.	Value of K.	Method of experiment.
Eiffel	6×18	20–33	·0029	Plate in a current of air.
Institute of Koutchino	4×12	9–18	·0029	" " "
Finzi and Soldati . .	4×12	22	·0032	See above.
Dines	4×16	21	·0036	" "
Langley	6×24	12–22	·0033	" "
Dines	6×24	21	·0036	" "
Eiffel	7×28	38–76	·0031	Falling plate.
"	6×34	20–33	·0030	Plate in a current of air.
"	6×36	20–33	·0030	" " "
"	4×36	20–33	·0031	" " "
"	1·9×19	20–33	·0031	" " "
Stanton	·3×4·5	14	·0034	" " "
Eiffel	1·6×24	20–33	·0034	" " "
Dines	3×48	40	·0035	Whirling machine, 28ft. radius
Hagen	1×16	4	·0032	" " 8 "
Dines	1×16	21	·0039	" " 28 "
Eiffel	1·35×27	20–33	·0036	Plate in a current of air.
"	·86×42	20–33	·0040	" " "
Stanton	·15×9	14	·0043	" " "
Circular plates.				
Stanton	2″ diam.	16	·0029	" " "
Institute of Koutchino	3″ "	2–14	·0032	" " "
Finzi and Soldati . .	4″ "	22	·0032	See above.
Dines	4½″ "	21	·0035	" "
Mannesman	5·8″ "	45	·0049	Whirling machine, 1⅝ft. radius.
Eiffel	6″ "	20–33	·0027	Plate in a current of air.
Cailletet and Colardeau	6″ "	47	·0028	Falling plate.
Hutton	6½″ "	7	·0034	Whirling machine, 4½ft. radius.
Renard	8″ "	0–100	·0042	" " 3⅝ "
Dines	9″ "	21	·0034	" " 28 "
Eiffel	11·3″ "	40–80	·0029	Falling plate.
"	12″ "	20–33	·0028	Plate in a current of air.
Finzi and Soldati . .	12″ "	22	·0042	Whirling machine, 15ft. radius.
Dines	13·54″ "	21	·0035	" " 28 "
Eiffel	16″ "	40–80	·0029	Falling plate.
"	22½″ "	40–80	·0031	" "
"	32″ "	40–80	·0032	" "
O'Gorman	36″ "	—	·0037	Plate towed through air.
Finzi and Soldati . .	39·37″ "	22	·0042	See above.
Canovetti	39·37″ "	17	·0031	" "
Von Lossl	43·3″ "	2	·0042	Whirling machine, 3¼ft. radius.

Notes on above.—The value of K determined by Marriote is that upon which Smeaton based his well-known formula $R = \cdot 005AV^2$. It gives too high a value of K, since the length of the whirling arm is small compared with the size of plate. The same remark applies to the results obtained by Thibault, Reichel, Von Lossl, Beaufoy, Renard, Mannesman, Hutton, and for the largest plates of Finzi and Soldati. The values given for the last two are for the medium line of the plate

and not for the whole, and for this reason the value of K is greater than if taken over the whole plate. The large value of K determined by Paris is probably due to too low a speed of the wind being taken. This was measured by an old-fashioned anemometer.

The value of K now usually employed for calculations of pressure on square or circular plates of medium size is ·003, in place of ·005 (the value given by Smeaton) formerly used. For large plates it is ·0032; for rectangular plates of medium size it is approximately given by $K = \cdot 003 + \cdot 000025n$, where n is the ratio of the longer to the short side.

VALUES OF THE COEFFICIENT K FOR OTHER BODIES.

Body.	Value of K.	Authority.	Remarks.
Sphere, 10″ diameter	·00015	Eiffel	—
" "	·00045	Renard	—
" 12″ "	·00100	Beaufoy	—
Hollow hemisphere, base first	·0035	Eiffel	—
Hemisphere, curved part first	·0008	"	—
Cone, vertical angle 60°, height = diameter, point first	·00013	"	—
Cone, vertical angle 80°, base = 16″, point first	·00008	"	—
Cylinder, moving base first	·00255	"	Length = diameter.
" " "	·0021	"	Length = $2\frac{1}{2}$ diameter.
Smooth wires	·0023	N.P.L. & Prandtl	—
Stranded wires	·0028 to ·0032	"	—
Perforated plate	·003	Dines	Plate 12″ × 12″ with 8–1″ holes.
" "	·0027	"	Plate 12″ × 12″, with 77 holes to sq. in., nett area 61 p.c.
" "	·0024	"	Holes 12 to sq. in., nett area 56 p.c.
" "	·00225	Canovetti	Plate $8\frac{3}{4}$ sq. ft., perforated with 8,000 holes, nett area 98 p.c.
" "	·00189	"	Plate $8\frac{3}{4}$ sq. ft., perforated with 106 holes, nett area 70 p.c.
Grating	·0005	—	Nett area 13 p.c.
Metal gauze	·00165	—	" " 70 p.c.
Trellis work	·00225	—	" " 60 p.c.
Struts	·00045 to ·003	N. P. L.	Depending on shape of section.

In the above the resistance is obtained by multiplying the coefficient by the (speed)² and maximum section perpendicular to the direction of motion. For the perforated plates, grating, gauze, etc., the coefficient is for the area of the containing figure.

In the case of struts the resistance varies considerably with the shape of section in the direction of motion. The best result obtained by the N.P.L. was with one whose length of section was six times the breadth, the greatest breadth being one-third the length from nose. The breadth half-way between nose and greatest breadth was ·9 the latter, and half-way between tail and greatest breadth was ·72 the latter. The nose and tail were sharp, and the area of section was 70 per cent of the containing rectangle. This gave the coefficient ·00045. Experiments carried out by N.P.L. for Ogilvie gave a smaller resistance than above with a strut whose length of section was 2½ times the maximum breadth. It had a flat nose and a somewhat bluff tail. Unfortunately both series of experiments were made at only one speed of air current, and it is quite possible that the best form at one speed may not be the best at another. Eiffel's experiments on struts show the coefficient of resistance diminishes as the speed increases, the diminution being different in different shapes. Results are therefore uncertain, and a great amount of experimental work is still necessary. The same remarks apply to the greater number of experimental results for bodies for which the eddy resistance is a large part of the total resistance.

Parallel plates moving normally.—Eiffel made experiments on circular discs, 12 inches diameter, one behind the other. The total force on the two is less than on one for intervals less than two diameters, the minimum being at about 1½ diameters interval where it is about three-fourths that on a single disc. For intervals greater than two diameters the total force is greater than on a single disc, but even at three diameters interval the total force is only 40 per cent greater than on a single disc. Similar results have been obtained by Stanton on 2″ and 1½″ dameter plates. For the former size the total force on both plates is twice that on a single plate when the interval between is about five diameters. For the 1½ in. plate the same is not obtained until a much greater interval is reached. The experiments show the extent of the shielding effect.

Frictional or skin resistance in air.—The most extensive series of experiments on skin resistance of bodies in air was made by Zahm. He used boards (maximum length 16 feet) with surfaces of dry varnish, wet sticky varnish sprinkled with water, calendered and uncalendered paper, glazed fabric, and sheet zinc. All gave the same results. Coarse buckram cloth gave 10 to 15 per cent greater resistance, and the latter varied as v^2 for speeds up to 25 miles per hour. His results are expressed by

$$\text{R in lb.} = \cdot 0000158 \times \text{area} \times \frac{V^{1\cdot 85}}{L^{\cdot 07}}$$

where L = length in feet, A = area of surface in square feet, and V is speed in miles per hour. Assuming the same law

as regards variation with length to apply to greater lengths, the following values of the coefficient are obtained.

Short lengths . . .	$K = \cdot0000158$.
15 feet lengths . .	$K = \cdot0000131$.
20 " " . .	$K = \cdot0000128$.
100 " " . .	$K = \cdot0000114$.
200 " " . .	$K = \cdot0000109$.
300 " " . .	$K = \cdot0000106$.
400 " " . .	$K = \cdot0000104$.
500 " " . .	$K = \cdot0000103$.

Expressed in terms of the area of surface and square of the speed, i.e. $R = KAV^2$, K has the following values :—

For short lengths $K = \cdot000009$.

For a length of 200 ft. $K = \cdot00000615$ between 40 and 60 m.h.p.

" " 300 ft. $K = \cdot000006$ " " "

" " 400 ft. $K = \cdot0000059$ " " "

" " 500 ft. $K = \cdot0000058$ " " "

Taking the formula $R = \cdot0000158 \times \text{area} \times \frac{V^{1\cdot85}}{L^{\cdot07}}$ the following table gives the coefficient which multiplied by the area gives the resistance in lb.

Length of Surface.	Values of Coefficient			
	at 30 m.p.h.	at 40 m.p h.	at 50 m.p.h.	at 60 m.p.h.
200 feet	·0059	·0100	·0152	·0212
300 ,,	·0057	·0097	·0147	·0206
400 ,,	·0056	·0096	·0145	·0203
500 ,,	·0055	·0094	·0142	·0200

Thurston's experiments on skin resistance were carried out on glass surfaces up to 4 feet long, and gave the following :—

$$R = \cdot0000098\ A\ (V^2 + 32\cdot22).$$

Franck's experiments carried out on surfaces swinging with a pendulum gave—

$$R = \cdot0000124\ AV^2.$$

Forces of Inclined Plates.

Before quoting results of experiments on inclined plates it is necessary to explain the following terms :—

Aspect ratio is the ratio of the dimension perpendicular to the direction of motion to the dimension parallel to the latter. Thus a plate 12 in. by 2 in., moving broadside on, has an aspect ratio of 6. The same plate moving endwise has an aspect ratio of $\frac{1}{6}$. The dimensions of a plate are always written with the side moving perpendicular

to the wind first, so that the aspect ratio is at once seen, i.e. a 36 in. by 6 in. plate is one moving broadside on, and has an aspect ratio 6. A 6 in. by 36 in. has an aspect ratio $\frac{1}{6}$.

The *lift* on a surface is the force on it, due to its motion relative to the air, in a direction perpendicular to that of motion. The *lift coefficient*, i.e. that coefficient which, multiplied by the product of area and square of speed to give the lift, is usually denoted by K_y.

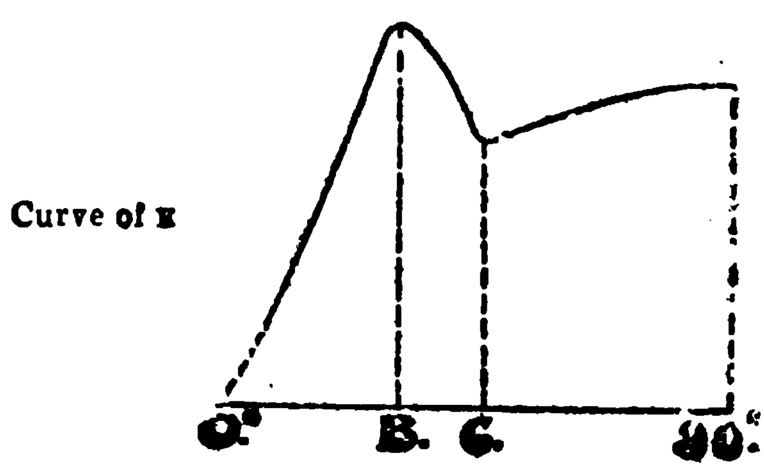
The *drift* is the force in the direction opposite to that of motion, i.e. the resistance. The *drift coefficient* is usually denoted by K_x.

The *total* or *resultant force* is the resultant of the lift and the drift, and its coefficient is usually denoted by K. On flat plates the resultant force acts sensibly normal to the surface. Skin friction and head resistance—especially the latter—cause a slight deviation from the normal. Eiffel's experiments showed that, at small angles, the deviation was appreciable. The plates used by him were, however, relatively thick—nearly one-eighth of an inch—the edges were not chamfered, and a sensible head resistance was thus caused. Experiments on plates with chamfered edges show the resultant force to be practically normal to the plate.

The value $\frac{\text{lift}}{\text{drift}}$ expresses the aerodynamical efficiency of the plate. The larger this ratio the greater the weight which can be lifted for a given resistance. The maximum value occurs at small angles varying for different shapes between 2° and 8°.

Critical angle.—If the resultant pressure coefficient is plotted on a base of angles of inclination a curve as shown in the figure is obtained for a thin flat plate. The curve

FIG. 283.



is generally a straight line from zero inclination up to an angle B. It then drops to a minimum at C. It then rises from C to 90°. The angle B is the *critical angle*. For a square plate it occurs at about 38°. As the aspect ratio

increases the critical angle diminishes, and the difference between the maximum and minimum values also decreases. For aspect ratios less than one the critical angle is above 38° and moves towards 90° as the aspect ratio diminishes. The portion between B and C also flattens out. A similar, but more exaggerated curve is obtained for curved plates. Since for aeroplanes the lift would suddenly diminish if the inclination exceeded the critical angle and would lead to difficulties, this angle is the practical limit of inclination of wings, and its corresponding lift coefficient defines the minimum speed at which the aeroplane can safely fly. In addition to the lift decreasing as the critical angle is passed, the drift also increases suddenly. The sudden change is caused by a change in the type of flow of the air over the surface. For angles less than the critical the streams on the front all pass along from the fore or *leading* edge to the after or *trailing* edge. For inclinations above the critical angle the streams on the front divide, some pass around the fore edge to the back regions, others pass direct to the after edge. At the critical angle the change in type of flow occurs, and at this angle the flow is unstable, and may be either one or the other. In such a case two different coefficients may be obtained at the critical angle. (See Göttingen results for a square plate at 40°.)

Experimental results.—In the following tables *the coefficient of resultant pressure* (K) is given. Units pounds, square feet, and miles per hour. The *lift and drift coefficients* can be obtained by resolution in the directions perpendicular to and parallel to the motion.

EIFFEL'S EXPERIMENTS (*La resistance de l'air et l'aviation*).
Speed of air about 27 miles per hour.

Aspect ratio.	Dimensions in inches.	Values of Coefficient K.								Position of critical angle and value of K at the angle.	
		6°	10°	20°	30°	40°	45°	60°	90°		
9	36×4	·00189	·0019	·0022	·0024	—	—	·0029	·00306	10°	·0025
6	36×6	·00111	·00175	·00212	·00237	—	—	·0028	·00302	15°	·0021
3	18×6	·00089	·00145	·00223	·0022	—	—	·0027	·0029	20°	·00223
2	12×6	·00075	·00124	·00263	·0020	·00224	—	·0026	·00286	21°	·00278
1½	9×6	—	·00111	·0023	·0023	·0024	—	·0026	·00277	26°	·0030
1	10×10	—	·00098	·0029	·0034	·0033	·00294	·0028	·00273	37°	·0039
⅓	6×18	·00033	·00061	·00147	·0026	·0035	·0035	·0031	·0029	43°	·00354
⅙	6×36	·0002	·0041	·0012	·0020	—	·0031	·0032	·0030	55°	·0032

The plates used were ·12 in. thick, with square edges.

Eiffel's experiments also showed that for similar plates

the ratio of the coefficient at an angle i (κ_i) to the coefficient at 90° remained constant. He proposed the following formula for angles of inclination up to 12°:—

$$\frac{K_i}{K_{90}} = \left(3 \cdot 2 + \frac{n}{2}\right)\frac{i}{100}$$

where i is the angle in degrees and n is the aspect ratio.

Göttingen results.—Plates all 14 in. measured in a direction parallel to motion.

Aspect ratio.	Values of Coefficient K.							Critical angle and value of corresponding coefficient.	
	10°	15°	20°	30°	40°	50°	60°		
3	·00186	·00233	·00235	·00244	·00275	·00314	—	18°	·00235
2	·00151	·00226	·00261	·00231	·00260	—	—	18°	·00266
1½	·00131	·00205	·00282	·00224	·00282	—	—	22°	·00295
1¼	·00114	·00185	·00260	·00391	·00292	·00314	—	33°	·00417
1	·00098	·00157	·00234	·00377	·0047 ·0029	·0090	—	42°	·00474
½	·00072	·00123	·00188	·00329	·0045	·0049	·0033	43°	·00468

In these experiments the under side of the plates was chamfered and the edges were very thin, and this probably explains the differences in the values of the coefficients as compared with Eiffel's results.

Institute of Koutchino's results—

Aspect ratio.	Dimensions.	Values of Coefficient K.						
		10°	15°	20°	30°	40°	50°	60°
3	12″×4″	·00115	·0017	·0021	·0024	·0023	·0024	·0025
1	12″×12″	·00088	—	·0018	·0027	·0028	·0027	·0027

Mr. R. E. Froude's results in water divided by ratio of densities of water and air—

Aspect ratio.	Value of Coefficient.						Critical angle and value of coefficient.	
	10°	15°	20°	30°	40°	90°		
1	·0011	·0017	·0024	·0034	·0029	·003	37°	·004
2	·0014	·0022	·0023	·0022	·0024	·0031	35°	·0028
½	·0009	·0012	·0018	·0033	·0033	·0032	50°	—

Centre of pressure.—The results of different experimenters differ in the position obtained for the *centre of pressure*. For motion perpendicular to the plate it must be at the centre.

As the inclination diminishes it moves slowly towards the leading edge of the plate until the critical angle is reached. As the angle is further diminished it moves rapidly towards the leading edge for aspect ratios above 1, and below 1 it moves very slowly until very small angles are reached.

The following shows *Eiffel's* results, the distance from the leading edge in terms of the dimension of the plate in the direction of motion being given :—

Aspect ratio.	Dimensions of plate in inches.	Distance of C.P. from leading edge.									
		5°	10°	20°	30°	40°	50°	60°	70°	80°	90°
6	36×6	·276	·34	·395	·406	·42	·43	·445	·455	·475	·5
3	18×6	·240	·30	·408	·420	·425	·435	·445	·46	·475	·5
1	10×10	·230	·26	·335	·385	·425	·435	·445	·455	·47	·5
$\frac{1}{3}$	6×18	·265	·30	·315	·325	·345	·35	·445	·455	·47	·5
$\frac{1}{6}$	6×36	·305	·32	·335	·335	·385	·38	·40	45	·465	·5

R. E. Froude's results in water—

Aspect ratio.	Distance of C.P. from fore edge.				
	10°	15°	20°	30°	35°
2	·245	·27	·305	·375	·40
1	·245	·31	·330	·400	·395
$\frac{1}{2}$	·257	·28	·295	·320	·330

Distribution of pressure.—The resultant pressure on a plate is due to an excess pressure on the front and a defect of pressure on the back. For small angles the latter is by far the greater, but as the critical angle is passed the back pressure becomes less important.

The following results were obtained by Eiffel, and show the pressure on the front as percentage of the total :—

	5°	10°	20°	30°	40°	45°	60°	90°
Square plate . .	26	24	23	24	29	43	55	68
Plate 34″ × 6″. .	[illegible]	22	22	31	44	—	[illegible]	67

So far as the actual distribution on the front and back of the square plate is concerned, measurements along the middle line show that for angles of inclination up to 20° the pressure on the back is all negative, and on the front all positive, the maximum values occurring in the vicinity of the leading edge, and diminishing very rapidly to the trailing edge. At 30° there is a slight amount of positive pressure on the back at the after edge, and the maximum defect pressure is at about one-third the length from fore edge.

At 35° the region of positive pressure on the back has increased, and also the maximum defect pressure. At 40° the same occurs. From 45° to 90° the defect pressure on the back is practically uniform over the whole length, but the maximum pressure at the leading edge on the front remains constant, and as the angle increases becomes uniform. At 90° the maximum pressure on the front is to the maximum defect pressure on the back as 69 is to 22.

From the 34 in. by 6 in. plate the pressure on the back is fairly uniform in distribution for angles from 20° to 90°. For 5° the maximum defect pressure is at leading edge, and rapidly diminishes to the after edge. At 10° the maximum is still at leading edge, but the pressure towards the after edge is much greater than at 5°. The positive pressure on the front is at all angles of inclination except 90° a maximum on the leading edge and diminishes rapidly toward the after edge, becoming negative at that edge for angles less than about 30°. At 90° the maximum pressure is at the middle, and is about 58 as compared with 22, the maximum defect pressure on the back.

The ratios given above for the maximum defect pressure on the back to the maximum excess pressure on the front are for the speed employed by Eiffel, viz. about 27 miles per hour. For other speeds it is probable that these ratios are altered.

Curved Plates.

For curved plates the inclination is taken as the inclination of the chord to the direction of motion. Unlike plane plates the curve of resultant pressure coefficient plotted on a base of angles of inclination of the chord does not pass through zero inclination. There is an appreciable value of the coefficient when the chord is parallel to the wind, and this does not become zero until a negative inclination is reached. This negative angle varies in different shapes. The resultant force is no longer in a direction normal to the chord. Since for aeroplane calculations it is only necessary to know the lift and drift coefficients and the position of the centre of pressure, these are the quantities measured in experiments. The resultant pressure can be determined in amount, direction, and position from these three quantities. The lift and drift coefficients having been determined for various angles it is also easy to construct a curve of $\frac{\text{lift}}{\text{drift}}$ or efficiency and thus to determine the most efficient angle for flying. Since for practical purposes the upper limit of the angle of inclination is the *critical angle*, it is usual in experimental investigations on the aerodynamical qualities of aeroplane wings to limit observations to angles just exceeding the critical angle.

Compared with plane plates curved plates possess far better aerodynamical qualities. This can be seen by comparing the lift and drift coefficients and also the values of $\frac{\text{lift}}{\text{drift}}$ for a plane plate 36 in. by 6 in., and one of the same size bent into a circular arc, the camber being $\frac{1}{13\frac{1}{2}}$ of the chord. The results are taken from Eiffel's book (*La résistance de l'air et l'aviation*).

		Values of Coefficients.						
		3°	6°	9°	10°	15°	20°	
Plane plate, 36 in. by 6 in.	K_x	·00013	·000175	·00029	·00034	·00054	·00074	Critical angle, 16°.
	K_y	·00055	·00103	·00165	·0017	·0020	·0019	
	$\frac{K_y}{K_x}$	4·2	6·2	5·7	5·0	3·7	2·5	
Curved plate, 36 in. by 6 in. Cambered $\frac{1}{13\frac{1}{2}}$	K_x	·00016	·00020	·00032	·00036	·0007	·001	Critical angle, 15°
	K_y	·00186	0023	·0028	·0029	·0031	·0028	
	$\frac{K_y}{K_x}$	11·6	11·5	8·7	8·1	4·4	2·8	

The angle at which the maximum value of $\frac{\text{lift}}{\text{drift}}$ occurs is for the plane plate 5°, and for the curved plate about 3°. At these angles the drift coefficients for the two plates are practically the same; the lift coefficient of the curved plate is 87 per cent more. Hence, if for a certain speed and drift the plane plate will lift 100 lb. the curved plate at the same speed and drift will lift 187 lb.

For a plane plate at angles below the critical angle the centre of pressure moves rapidly towards the leading edge as the angle of inclination diminishes. This is an advantage, since if from any cause the angle of inclination diminishes the movement of the centre of pressure forward tends to increase the angle. A plane plate possesses inherent stability for this reason. On the other hand, with a cambered plate the centre of pressure at inclinations below the critical angle moves rapidly towards the rear edge as the angle is diminished.

For the curved plate given above the centre of pressure moves as shown below:—

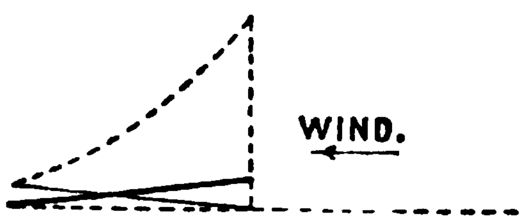
Angles of Inclination of Chord:	0°	5°	10°	15°	17°	20°
$\dfrac{\text{CP from fore edge}}{\text{Length (6'')}}$ . .	·53	·44	·37	·36	·40	·43

It will be noted that at the critical angle the centre of pressure is nearest the leading edge. For angles greater and less it is further aft.

If such a curved plate were used as an aeroplane wing, and for some cause the angle of inclination diminished, the movement of the centre of pressure is such as to still further diminish it. The curved plate is thus unstable, and stability must be obtained by independent elevating planes. This is common to all unicurved plates, and is the only disadvantage as compared with the plane plate.

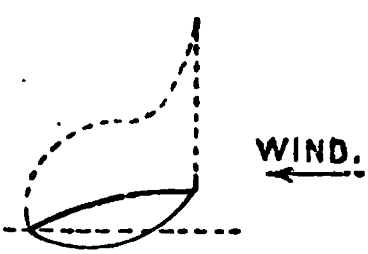
The advantage in the aerodynamical qualities of the curved as compared with the plane plate is due principally to the greater negative pressures on the back. This is best seen from the figures below showing the curves of pressure over the medium section obtained by Eiffel for the two plates mentioned above and at 6° inclination.

FIG. 234.



DISTRIBUTION OF PRESSURE ON PLANE PLATE.

FIG. 235.



DISTRIBUTION OF PRESSURE ON CURVED PLATE.

The dotted lines show the curve of pressure over the back, the base lines being the planes themselves. The lower full lines show the pressure on the front of plate. In the plane plate the pressure on the front becomes negative just abaft the middle, whilst for the curved plate it is positive except for a small portion at the after end. In both cases the negative pressure extends over the whole back. The resultant pressure at any point is the intercept between the dotted and full curves, and the shapes of the curves in the two cases explain the difference in the distances of the centre of pressures from the fore edge.

Experiments on Curved Plates.

Since the curved plate has such marked aerodynamical advantages over plane plates, experimental investigation has been devoted to obtaining that section from which the best results are to be obtained. It is evident that for a curved

plate very many variations can be obtained, i.e. the aspect ratio, the camber, the thickness of the wing, etc., can all be varied. The following tables give particulars of results on variation of *aspect ratio* :—

Authority.	Aspect ratio.	Angle of maximum $\frac{\text{lift}}{\text{drift}}$ in degrees.	Value of maximum $\frac{\text{lift}}{\text{drift}}$	Value of lift coefficient at maximum $\frac{\text{lift}}{\text{drift}}$	Remarks.
N.P.L. .	5	4	7·6	·00071	Plane plates.
„ .	4	4	7·6	·00063	
„ .	3	4	7·6	·00058	
Göttingen Inst. .	4	4	7·6	·0015	Plane plate, bevelled edges.
Eiffel .	6	5¾	6·4	·00106	Plane plate, square edges
„ .	1	5	6·0	·00045	„ „ „
Koutchino Inst. .	3	6	9·2	—	Plane plate, bevelled edges.
N.P.L. .	3	5½	10·1	·00155	Camber of upper surface $\frac{1}{12}$; of lower $\frac{1}{24}$; maximum camber at ¼ length from fore edge; critical angle about 14° in all cases. Maximum lift coefficient about ·0031.
„ .	4	4·7	11·5	·00159	
„ .	5	4·7	12·9	·00160	
„ .	6	4·5	14·0	·00160	
„ .	7	4·7	15·1	·00160	
Göttingen	1	6·0	4·8	·00106	Plates bent into circular arc camber $\frac{3}{40}$ chord. Critical angles varied from 40° for aspect ratio 1 to 12½° for aspect ratio ∞ lift coefficient at critical angle varied from ·0025 to ·0036 as aspect ratio increased from 1 to ∞.
„	1¼	5·0	6·0	·00122	
„	2½	4·75	8·0	·00171	
„	4	5·0	9·8	·00228	
„	5½	4·75	12·1	·0024	
„ (by interpolation)	Infinite	4·75	19·0	·0028	

The results show that the effect of increasing the aspect ratio of curved plates is to increase the efficiency, and also the value of the lift coefficient at the angle of maximum efficiency. The critical angle decreases, but the value of the lift coefficient at this angle increases. For flat plates the effect of increasing the aspect ratio is small compared with that for curved plates.

In practice a very large aspect ratio cannot be employed, since it involves more supporting wires, etc., to meet the greater forces on the wings. The drift is thus increased without alteration of the lift, and the $\frac{\text{lift}}{\text{drift}}$ is reduced below that of the experimental results. It is therefore rarely the case that in an actual aeroplane the aspect ratio is above 6 or 7.

EFFECT OF ALTERATION OF LOWER SURFACE.							
Authority.	Aspect ratio.	Camber of upper surface.	Camber of lower surface.	Angle of max. L/D.	Value of max. L/D.	Value of lift at max. L/D.	Critical angle.
N.P.L.	6	$\frac{1}{10}$	0	4°	12·8	·00176	$11\frac{1}{2}$°
,,	6	$\frac{1}{10}$	$\frac{1}{50}$	4°	12·9	·00186	$11\frac{1}{4}$°
,,	6	$\frac{1}{10}$	$\frac{1}{25}$	4°	12·3	·00191	$11\frac{3}{4}$°
,,	6	$\frac{1}{10}$	$\frac{3}{50}$	4°	12·8	·00206	$11\frac{3}{4}$°

The results show that there is no great alteration in the aerodynamical qualities by alteration of the lower surface. This is almost self-evident, since the greater part of the lift and drift is caused by the negative pressure on the back. The form of the leading edge modifies this to some extent, but this form is not greatly altered by changes in the shape of the lower surface.

EFFECT OF ALTERING THICKNESS.						
Authority.	Aspect ratio.	Dimensions.	Max. thickness.	Angle of max. $\frac{\text{lift}}{\text{drift}}$	Value of max. $\frac{\text{lift}}{\text{drift}}$	Value of lift at max. $\frac{\text{lift}}{\text{drift}}$
		inches.	inch.			
Eiffel	6	36×6	·4	$2\frac{1}{2}$	11·2	·0015
,,	6	36×6	·56	3	10·0	·0014
,,	6	36×6	·72	3	10·0	·00138

EFFECT OF VARYING THE POSITION OF MAXIMUM ORDINATE (N.P.L.).					
Position of maximum ordinate.	Maximum $\frac{\text{lift}}{\text{drift}}$			Critical angle.	
	Angle of	Value.	Lift coefficient.	Angle.	Lift coefficient
·500	$7\frac{1}{2}$	11·2	·00237	18	·00316
·380	5	13·2	·00189	18	·00316
·355	4	13·6	·00173	17	·00344
·332	4	13·9	·00164	16	·00360
·310	4	13·9	·00170	13	·00308
·292	4	13·4	·00170	$11\frac{1}{2}$	·00286
·252	4	12·7	·00155	$10\frac{1}{2}$	·0027
·220	4	12·0	·00153	9	·0023
·168	$4\frac{1}{2}$	11·1	·00148	$8\frac{1}{2}$	·0021

Plate employed 15 in. by 2½ in. with flat lower surface and an upper surface cambered ·25 in. The position of maximum camber was varied, and in column 1 is given its distance from fore edge in terms of the chord.

Results show that as the maximum ordinate is moved forward from the middle the maximum value of $\frac{\text{lift}}{\text{drift}}$ first increases and then diminishes, the angle of maximum $\frac{\text{lift}}{\text{drift}}$ first decreases and then remains constant; the critical angle diminishes, and with it the corresponding value of the lift coefficient. In the case of the first and second the critical angle was not so marked as for the others, the curve of lift coefficients to base of angles of inclination being a fair curve up to 24°. In the others there is a marked fall at the critical angle, especially in the case of the third and fourth, for which the coefficients decrease 22 and 30 per cent for 1° or 2° beyond the critical angle, and in the next few degrees attain nearly the same value as at the critical angle.

For the particular type of section tried the best aerodynamical qualities are obtained with the maximum ordinate at about one-third the chord from the leading edge.

Effect of Varying Shape of Leading and Trailing Edges (N.P.L.).

For effect of variation of leading edge four wings were tried each 15 in. by 2½ in. in plan. The upper and lower surfaces were cambered ·25 in. and ·15 in. respectively at one-quarter the chord fom leading edge. The shape abaft this was the same in all, the forward portion alone being altered. The fore edge of the first was pointed, the three others were rounded, the lower front surface of the wings being brought in fair with the nose. The diameters of the three rounded fore edges were ⅔, 1, and 4/3, the maximum thickness of the wing (·10 in.).

Section at nose.	Maximum $\frac{\text{lift}}{\text{drift}}$			Critical angle.	
	Angle.	Value.	Lift coefficient.	Value.	Lift coefficient.
Sharp	4	12·8	·00204	11½	·0034
Diameter ⅔ thickness	4	11·5	·00214	12	·0037
,, 1 ,,	4	11·1	·00204	11	·0032
,, 4/3 ,,	2	10·4	·0016	9	·0027

The sharp-edged section thus gave the best results.

Experiments on a wing in which the section at trailing edge was gradually fined away on the upper surface showed that as the thickness was reduced the aerodynamical qualities improved.

Distribution of Pressure on an Aeroplane Wing.

Experiments at N.P.L. made on a wing 18 in. by 3 in. whose lower surface was cambered $\frac{8}{100}$ in., and upper surface ·26 in., maximum camber at $\frac{3}{10}$ chord from front edge. Sections taken at (*a*) midd'e, (*b*) $\frac{1}{8}$, (*c*) $\frac{1}{12}$, (*d*) $\frac{1}{18}$, and (*e*) $\frac{1}{180}$, the span from the tip of the wing. Pressure measured at seven positions both on upper and lower surfaces at each section.

The results show that the maximum pressures both on front and back occur at the leading edge at all sections except (*e*) and at all inclinations, and diminish to zero at the trailing edge. The maximum defect pressure on the upper and excess pressure on the lower surface are on section (*a*) and decrease as the tip of the wing is approached. They increase in amount as the angle of inclination is increased. At (*e*) the section near the tip, the pressure distribution at angles $-2°$ to $2°$ is nearly uniform, but for angles above $2°$ the maximum pressure is near the after edge. Generally, for all positive angles and for all sections except (*e*) the pressure on the back is negative and on the front positive. For section (*e*) the pressure is negative both on front and back for positive inclinations except for a small distance near the leading edge.

By resolution and integration of the pressures the lift and drift at each section were obtained. The lift at A is $\frac{1}{7}$ greater than at B, $\frac{1}{3}$ greater than at C, $\frac{6}{11}$ greater than at E, and $\frac{3}{8}$ greater than at D. The maximum value of $\frac{\text{lift}}{\text{drift}}$ is 24 at A, 18 at B, 13 at C, $8\frac{1}{2}$ at D, and 5 at E, and for the wing considered as a whole 17·8. These figures neglect skin friction, which, when allowed for, gives a maximum value of $\frac{\text{lift}}{\text{drift}}$ of 20 at A and 15 for the whole wing.

The position of the centre of pressure is different at each section. For A it is ·27 of the chord from fore edge at 12° and ·49 at 0°. For B and C sections it is slightly further from leading edge at all angles, and for D still further except at 2° and below when it is nearer than for A. For section E it is ·52 the chord from leading edge at 12° : ·66 at 0°.

Eiffel's experiments were made on the model of a Nieuport monoplane wing cambered both front and back and whose

thickness diminished at the tip. Observations made at 2° and 6°. Sections taken—

(*a*) near connexion of wing to fuselage.
(*b*) about half-way between fuselage and tip of wing.
(*c*) „ $\frac{7}{8}$ „ „ „ „
(*d*) „ $\frac{19}{20}$ „ „ „ „

Results for 6° show that pressure on the back was a maximum for section (*a*) and gradually diminished to the tip, being, however, a defect pressure at all points on the back in all sections. The position of maximum defect pressure was at ·28 chord from leading edge on section (*a*), the pressure diminishing towards front and rear. For other sections the position of maximum defect pressure was slightly further aft. The pressure on the front or lower surface was an excess pressure on all sections except just near the edges. It was a maximum on section B and diminished gradually to the tip. The position of maximum pressure was about ·3 of the chord from fore edge. At 2° the distribution was very similar to that at 6°, except that near the leading edge the pressure on the front or lower surface was a defect pressure for a greater distance than at 6°. The maximum defect and excess pressures were less at all sections than at 6°.

Sections with Reverse Curvature at the Trailing Edge.

The foregoing experimental results deal with plane plates or unicurved sections, i.e. the section wholly concave to the chord. Eiffel and the N.P.L. have carried out experiments on sections, in which the after portion of the section was curved in the opposite direction, i.e. convex on the lower side.

Eiffel first used a section of uniform thickness, the after half being curved equally, but in the opposite direction to the front half, which was concave to the chord. His results showed that (1) the lift and drift coefficients at any particular angle decreased as the speed increased, but the drift decreased more quickly than the lift, and hence the value $\frac{\text{lift}}{\text{drift}}$ increased with the speed, (2) the aerodynamical qualities were less favourable than in unicurved sections, and (3) the centre of pressure moved towards the leading edge as the inclination decreased. The latter effect is similar to that for a plane plate, but the reverse of that in a unicurved wing.

Further experiments by M. Eiffel on a section similar to an ordinary aeroplane section except that it had an upturned trailing edge gave similar results. The speed of experiment was varied from 6 to 14 miles per second, the drift and lift coefficients at 8° being ·00017 and ·00136 at the lower and ·00014 and ·00122 at the higher speed. The centre of pressure was ·34 of the chord from front edge at 20° and ·07 at 0°.

The N.P.L. experiments were carried out using as basis a wing whose section was slightly cambered on the lower surface, and well cambered on the upper surface. The other sections were obtained by raising the trailing edge starting from a distance ·4 of the chord from the latter. In the table the rise of tail is given in terms of the chord.

Section.	Rise of tail.	Maximum $\frac{\text{lift}}{\text{drift}}$			Critical angle.	
		Angle.	Value.	Lift coefficient.	Angle.	Lift coefficient.
1	0	3	15·8	·00138	16	·0032
2	·011	3½	15·0	·00107	18	·0029
3	·027	5¼	14·3	·00122	16	·0027
4	·057	10	12·8	·00145	16	·0024

In 1, 2, and 3 the centre of pressure moved aft as the angle of inclination decreased, but this movement was slower as the tail was raised higher, and in 4 the centre of pressure moved forward as the angle decreased. The great advantage of reverse curvature of the tail is that it gives stability, but this is obtained by the sacrifice of other qualities.

Biplane Effects.

The foregoing results have been obtained with single plates. In the case of two similar parallel plates close to one another as in a biplane, each has an effect on the other and the aerodynamical qualities are altered.

Langley was the first to experiment with pairs of similar plates, 15 in. by 4 in. spaced 2 in., 4 in., and 6 in. apart. The weights for the three spacings were the same, and the speeds at which they were self-supported were compared with that of a single plate of half the weight at the same angle of inclination. The results showed that for a 2 in. spacing an appreciably greater speed was necessary for self-support than for a single plate, and for 4 in. and 6 in. spacing the speed was the same. The apparatus employed was not, however, capable of very accurate measurements.

Eiffel's experiments were made on biplanes formed of (1) two similar parallel plane plates each 36 in. by 6 in., (2) two curved plates each 36 in. by 6 in. cambered ⅜ in. The spacings tried were 4 in., 6 in., and 8 in. in both sets.

Pressures taken at various points at the medium longitudinal sections of both plates when inclined 6° show that for the plane plates the pressures on the front and back of

both plates are for all spacings less than on a single plate except in the case of the lower surface of the bottom plate for 4 in. and 6 in. spacing where in the first case it is greater and in the second the same as for a single plate. In the case of the curved plates the defect pressure on the back surface of the upper plate is increased for the 6 in. and 8 in. spacing. The pressure on the front of the upper plate is also increased for 8 in. spacing, and is the same as for a single plate for 6 in. spacing. For the lower plate at the three spacings the pressures on back and front are less than for a single plate.

Results.						
	Lift coefficients. Plane plates.			Lift coefficients. Curved plates.		
	3°	6°	9°	1°	3°	6°
Single plate	·00055	·00109	·00165	·0012	·0017	·00237
Spaced 4 in.	·00028	·0007	·00106	·0011	·00134	·00175
„ 6 „	·0003	·00077	·00117	·0012	·00143	·00184
„ 8 „	·00037	·00082	·00124	·0012	·00153	·00196

The N.P.L. experiments on the same point were made on a Bleriot section of wing 20 in. by 5 in. The table gives the ratio of the lift coefficient to that for a single similar wing.

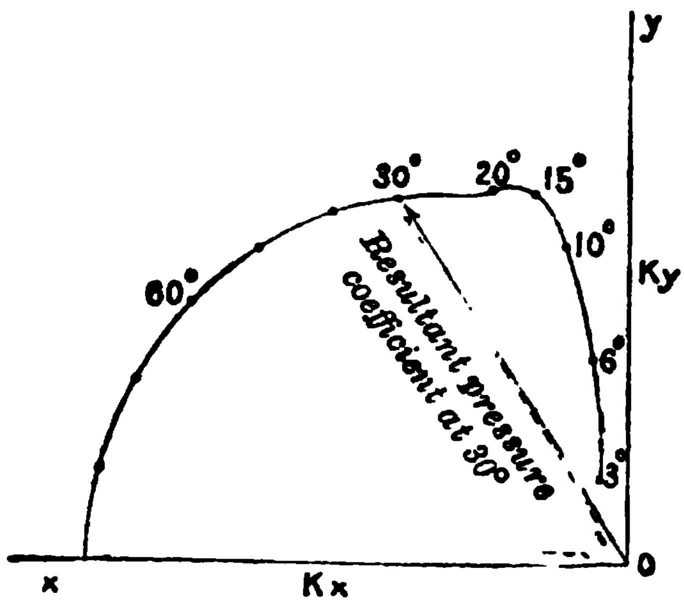
Spacing.	Ratio of lift coefficient to that of a single wing.		
	6°	8°	10°
2 in.	·61	·62	·63
4 in.	·76	·77	·78
5 in.	·81	·82	·82
6 in.	·86	·86	·87
8 in.	·89	·89	·90

The lift coefficients are thus smaller than for a single similar wing even at the largest spacing. Since, however, increase of spacing between the wings involves increase in the lengths of struts and bracing wires thus increasing the drift, when this is taken into account, the best spacing appears to be equal to the chord of the wings.

Method of representing Experimental results.

The method employed by Eiffel offers many advantages. It was first employed by Lilienthal, and consists in taking two rectangular axes OX and OY, and setting off a vector from the origin O in magnitude and direction equal to the coefficient and the resultant pressure on the wing. The lift coefficient K_y and the drift coefficient K_x are then the projections of the coefficient of the resultant on the axes of OY and OX respectively. If this is done for various angles of inclination a curve as shown is obtained.

FIG. 236



Polar diagram of resultant pressure.

The angles marked on the curve correspond to the angles of inclination of the plate, and are generally not on the lines drawn through the origin at an angle from OY equal to the inclination, since the resultant pressure does not generally act in a direction normal to the chord.

In addition to the above curve a second set of curves showing the resultant pressure coefficient (K), the lift coefficient (K_y) and the drift coefficient (K_x) is drawn to a base of angles of inclination. A third set of curves shows the position of the centre of pressure at various angles of inclination.

If in the curve shown above a tangent is drawn from the origin touching the curve this line gives the direction of the resultant force for $\frac{\text{lift}}{\text{drift}}$ to be a maximum, and the tangent of the angle this line makes with OX gives the maximum value of $\frac{\text{lift}}{\text{drift}}$. The actual angle of inclination is found by measuring the corresponding value of the resultant

coefficient setting this up on the curve of K to a base of inclinations and measuring the corresponding angle.

Method of Calculation.

In an actual aeroplane there are, besides the wings, other parts which offer resistance to motion without contributing any support. The result is that the drift coefficient for the whole machine is much greater than that of the wings, whilst the lift coefficient is that of the wings alone. The resistance of the wings alone is termed the *active resistance*, since it is a necessary complement of the lift. The resistance of the remainder of the machine and from which no lift is obtained is termed the *passive resistance*. It is generally expressed in terms of the area of a square plate which, moving normally at the same speed, will give an equal resistance. This equivalent plate is termed the *detrimental surface*. If, therefore, the wing surface is S and the detrimental surface S^1, K_y the lift coefficient, K_x the drift coefficient of the wings alone, the total resistance is given by

$$R = K_x S V^2 + \cdot 0032\, S^1 V^2,$$

where V is the speed in miles per hour, S and S^1 are in square feet, and ·0032 is the resistance coefficient for a square plate. The lift is given by $L = K_y S V^2$.

The resistance can be expressed in the form

$$R = SV^2\left(K_x + \frac{\cdot 0032 S^1}{S}\right),$$

and the lift by $L = SV^2 K_y$.

$\frac{L}{R}$ is a maximum when $\dfrac{K_y}{K_x + \dfrac{\cdot 0032 S^1}{S}}$ is a maximum. The angle at which this expression is a maximum can be determined from the resultant pressure vectorial curve of the wing by setting off a distance $00^1 = \dfrac{\cdot 0032 S^1}{S}$ from the origin to the right along OX. By drawing a tangent to the curve the angle at which $\dfrac{K_y}{K_x + \dfrac{\cdot 0032 S^1}{S}}$ is a maximum can be obtained.

Mathematically it can be proved that the expression is a maximum when the active resistance is equal to the passive, i.e. $K_x = \dfrac{\cdot 0032 S^1}{S}$

If the weight (W) to be lifted is known the speed for maximum value of $\frac{L}{R}$ can be found since $W = K_y S V^2$, and thus

$v = \sqrt{\frac{W}{K_y S}}$ of which W, S, and K_y are known. The speed being known the resistance and effective horse-power required can be calculated.

The minimum speed at which the aeroplane can be flown is determined by the value of the lift coefficient corresponding to the critical angle. If this be denoted by K^1_y the minimum speed is given by—

$$v_1 = \sqrt{\frac{W}{K^1_y s}} \text{ or } \frac{v}{v_1} = \sqrt{\frac{K^1_y}{K_y}}$$

Thus if the lift coefficient at the critical angle is twice that at the angle of maximum $\frac{\text{lift}}{\text{drift}}$ the minimum speed will be $\frac{1}{\sqrt{2}}$ or 71 per cent of that at speed for maximum $\frac{\text{lift}}{\text{drift}}$

The above are simple calculations in connexion with aeroplane work. There are others which are far more complicated and for which reference must be made to works on the subject.

It may be mentioned that the *detrimental surface* as determined by Eiffel for a full-sized R.E.P. monoplane is one square metre, and for a Nieuport monoplane two-thirds square metre. For a B.E. 2 aeroplane it is 7·6 square feet.

Comparison between Results of Model and Full-sized Machines.

Mathematicians have shown that the two resistances operating in airships and aeroplanes—skin friction and eddy resistance—are in similar bodies moving in air strictly comparable when the product LV is constant. L is a dimension and V the speed. If the dimensions of a model are one-twentieth those of the airship or aeroplane and the speed of the latter is 50 miles per hour, the model results are only strictly applicable to the full-sized machine when the model velocity is 1,000 miles per hour. This speed is impracticable. If, however, another medium is employed similar motions obtain if $\frac{LV}{v}$ is constant where v is the coefficient of kinematic viscosity. Since the value of this for water is thirteen times the value for air, it is possible to compare results obtained from similar models in air and water by regulating the speeds in accordance with the law. So far the law has been experimentally verified for skin friction, but not for eddy resistance.

The variation of the various coefficients (lift, drift, etc.) with the speed has not received great attention, experiments

in each laboratory having been carried out generally at one speed, and although the speeds may be different in different laboratories other features have prevented a strict comparison between the results. Generally speaking, the speed of experiment is limited by the size of the wind tunnel. Larger wind tunnels have, however, been recently constructed by Eiffel and at the N.P.L., thus permitting of higher speeds and possibly in the near future much more information will be available on this important point.

Eiffel's early experiments with plates falling under the action of gravity showed that the coefficient of resistance for a plate of one square metre area was 10 per cent greater than for a plate of $\frac{1}{100}$ square metre area. In the first edition of his book *La résistance de l'air et l'aviation*, he recommended that results obtained from model experiments should be increased 10 per cent for application to full-sized aeroplanes. In a later edition he recommends that the model results should be applied without correction. This suggestion is based on a comparison of the results obtained from an aeroplane and those obtained on a complete model in his laboratory. The published comparison of these results show that the maximum difference is only 5 per cent and the mean difference about 2 per cent. The comparison is not, however, conclusive, since it might be expected that with the propeller working in the aeroplane and not in the model much greater differences than 5 per cent would result.

Experiments have recently been carried out on a model of an aeroplane wing at the N.P.L., the speed being varied over a fairly large range. The wing employed was 15 in. by 2½ in. and the speeds 7, 10½, 14, 21, 28, and 35 miles per hour. The lift and drift coefficients were measured at every 2° up to 20° inclination at each speed.

The results show that as the speed increased the lift coefficient increased for angles up to 6° inclination, and that for speeds between 14 and 35 miles per hour it remained constant for angles of inclination from 6° to 14°. From 14° to 20° the lift coefficient increased as the speed increased, but this was apparently due to the fact that the critical angle also increased with the speed and at 14° the critical angle for the lower speeds was passed; the lift coefficients decreased rapidly in value for these lower speeds, but not so quickly for the higher speeds. The run of the curves would appear to indicate that at angles above 20° the lift coefficient decreases as the speed increases, a point which will be referred to later.

The drift coefficient decreased as the speed increased for all angles up to about 20°. At this angle the values for 14, 21, 28, and 35 miles per hour are the same, but for 7 and 10½ m.p.h. they are less than for the others. The net effect of the alteration in the lift and drift coefficients is that as the

speed increases the maximum value of $\frac{\text{lift}}{\text{drift}}$ increases from 10·5 at 7 m.p.h. to 17·6 at 35 m.p.h. The angle at which this occurs is 7° at 7 m.p.h. and 3° at 35 m.p.h. From the curves it looks quite probable that at higher speeds than 35 m.p.h. the angle of maximum $\frac{\text{lift}}{\text{drift}}$ will still further diminish and the value of the latter increase. The critical angle increases from 11° at 7 m.p.h. to 15° at 35 m.p.h.

These results are similar to those obtained by Eiffel on a model wing of a Nieuport monoplane inclined at 3°, the speed being varied from about 12 to 36 miles per hour. The lift coefficient increased and the drift coefficient decreased about 6 per cent for this range of speed. This compares with differences between results at 7 and 35 m.p.h. of about 40 per cent in the case of the N.P.L. experiments at the same angle.

In the case of a wing of reverse curvature Eiffel found that both the lift and drift coefficients decreased as the speed increased, but since the drift coefficient decreased at a greater rate than the lift the efficiency increased with the speed.

It seems evident, therefore, that for different shapes of sections the effect of increase of speed on the aerodynamical qualities may be greatly different, and no general law can be deduced from the results of a particular wing. A great amount of experimental work is therefore necessary before a general law can be enunciated. It seems clear, however, that generally if model results are used for design work the resulting aeroplane will possess better aerodynamical qualities than the model. It would also appear that the greater the model speed the more closely will the results agree with those of the aeroplane.

A second series of experiments was carried out at the N.P.L. to compare model results with those obtained on full-sized wings in the Laboratory at St. Cyr in France. The models were placed in a current of air with a speed of about 34 miles per hour, and the lift coefficients so found at 2° to 6° inclination compared very favourably with those on the full-sized wings. The drift coefficients were, however, much smaller.

The N.P.L. therefore concludes from this and other experiments that the lift coefficients from model experiments at fairly high speeds will apply to the full-sized wings, but that 15 to 20 per cent must be added to the maximum $\frac{\text{lift}}{\text{drift}}$ of the models to obtain the value in the full-sized wing.

As before mentioned, the N.P.L. experiments on variation of coefficients, etc., with speed were only carried to 20°

inclination. It would appear from the run of the curves that for angles of inclination greater than the critical angle, at which inclination the type of flow changes, the law of variation with speed is different, and that the lift coefficient decreases with increase in speed. On this point the results of experiments made at the Institute at Koutchino on a square plate at different speeds are of interest. At angles less than the critical the normal pressure coefficient increased with the speed, but for inclinations greater than the critical angle it decreased as the speed increased.

Final Note.—The experimental results given in the foregoing form the basis of aeroplane design. For details of actual aeroplanes and for detailed calculations as to the strength and other qualities, reference must be made to books and periodicals dealing with such matters. Much fuller experimental information is also given in Eiffel's classical work, which has been quoted, and in the reports of the Advisory Committee on Aeronautics.

The results of experiments in air are of some practical importance to Naval architects, since the problems connected with submarines, propellers, rudders, etc., are similar to those in connexion with airships and aeroplanes. The results, so far as coefficients are concerned, are applicable to water by multiplying their values by 832 for sea water or 810 for fresh, these numbers representing the ratios of the densities of water to air.

AERONAUTICS.

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Airships.

Airships are divided into three classes:—

1. *Non-rigid*, in which the car is hung directly by ropes or wires from the envelope, the ropes being so arranged that the load is spread as evenly as possible over the greater portion of the length of the envelope. The upper ends of these ropes are secured to bands of fabric encircling the envelope, or to strips of fabric fastened to the envelope along the intersection of a horizontal diametral plane. The strength of such an airship depends entirely upon the strength of the fabric of the envelope. The spherical balloon is the most elementary form of this type, the car being suspended from a network of rope encircling the upper portion of balloon.

2. *Semi-rigid*, in which a framework of steel or aluminium-alloy rods is attached to the lower portion of the envelope. To this framework is attached the cars carrying the engines, fuel, crew, and other loads. It extends in some cases the

whole length of the envelope, and the straining actions on the airship are to a great extent taken by it, instead of on the fabric of the envelope as in the non-rigid type.

In both types, i.e. non-rigid and semi-rigid, the shape of the envelope is maintained by an internal excess pressure. This excess pressure causes all parts of the envelope to be in tension, and so long as the straining forces on the airship produce compressive forces less than the tensile, the envelope retains its shape. If the compressive stresses are greater than the tensile stresses caused by the excess pressure, the portion of the envelope concerned will collapse. Since, therefore, the whole strength of the non-rigid and the shape of the aerostat of the semi-rigid depends on this excess pressure, and the hydrogen with which the envelope is inflated is always permeating through the fabric it is necessary to provide means for maintaining the excess pressure. This is done by fitting expansible internal compartments termed 'ballonets', which are connected by trunks to a fan in the car. At the start of a voyage the ballonets have little air in them, but as the hydrogen is lost the volume of the ballonets increase so that the envelope remains distended, and the same excess pressure is maintained inside. This excess pressure is generally from 10 to 25 millimetres of water (i.e. 2·1 to 5·2 lb. per square foot). In some designs there is a ballonet at each end of the airship, the total volume being from one-fourth to one-seventh the volume of the envelope. In the Siemens-Schukert design (non-rigid), in which the envelope is divided by two transverse bulkheads into three parts, there is a ballonet in each part. In the Forlanini (semi-rigid), two concentric envelopes are fitted, and the annular space between the two forms the ballonet. Safety-valves, which blow off automatically when the internal pressure exceeds the designed pressure, are fitted to the ballonets and to the envelopes, and these valves are also arranged to be worked from the car by ropes or wires. They are also used when the airship rises to higher altitudes, and the gas expands due to the diminution of the outside pressure.

The ballonets when fitted one at each end can also be used for steering in a vertical plane by pumping air from one into the other. In other designs, movable weights are fitted for the same purpose, and in another the car itself can be shifted along longitudinally by suitable arrangements in the suspension wires. A shift of the car is also necessary to counterbalance the tilting moment on the airship caused by the line of thrust of the propeller being below the line of action of the resistance.

3. *Rigid*, in which the form of the airship is maintained by a rigid framework of transverse and longitudinal members

well connected together at the joints. The Zeppelin design is the most successful airship of this type, and the following remarks apply more particularly to that design. A keel of triangular section is fitted at the bottom, and to this are suspended the cars with the engines and propellers, fuel, ballast, etc. The transverse section is not circular as in non-rigids and semi-rigids, but a regular polygon of fifteen, sixteen, or seventeen sides, the lowest side being horizontal and forming the upper side or base of the triangular keel. The transverse frames are from 25 to 30 feet apart, and are built in short lengths corresponding to the sides of the polygon.

Wire bracing is fitted between each joint of a transverse frame and the two lowest joints, and serves to transmit the lift of the gas-bags. Radial bracing is also sometimes fitted. The longitudinal frames extend the whole length of the ship, their positions corresponding to the corners of the polygon, at which they are strongly connected to the transverse frames. At the bow and stern they are connected to conical plates or castings. Wire bracing is fitted in the rectangular spaces formed by adjacent longitudinal and transverse frames. Additional partial transverse frames and wire bracing are fitted in wake of the propeller brackets.

A light fabric cover is fitted on the outside of the framing to form a fair surface. Cylindrical gas-bags are fitted between the bracing of the transverse frames. The lift of these gas-bags is transferred to the framing by a rope network fitted on the inside of the framing. Since adjacent gas-bags are separated by the wire bracing of the transverse frames this has to take the strain when one gas-bag becomes deflated and the adjacent one is inflated. Valves are fitted in each of the gas-bags, and these work automatically and by wires from the cars. Pressure gauges showing the pressure of gas in each bag are fitted in the cars.

In the rigid type of airship the strains coming on the structure due to differences in distribution of the buoyancy and weight are taken by the keel by transmission through the frames. The transverse forces due to the wind or other causes, are taken on the framework or its wire bracings. No stresses other than those due to the excess pressure of gas in the bas-bags comes on the material of the latter. So far as the shape of the airship is concerned the gas-bags may be fully or partially inflated. In the latter case the distribution of buoyancy is altered.

Since the total buoyancy and weight of the airship are small it necessarily follows that the framing must be light and efficient. The longitudinal frames, which are only supported by the transverse at every 25 to 30 feet, tend to deflect outwards by the excess pressure of the gas-bags. Tensile forces on

these longitudinals are not difficult to meet since they tend to diminish the deflection of the frames due to the gas pressure.

Compressive forces are those which are most difficult to provide against, since the thin material of the girders tends to buckle under compression, and the tendency is increased by the deflection due to the pressure of the gas. To withstand these compressive stresses it is necessary that the inertia of the girder section and also the modulus of elasticity of the material should be as large as possible for the weight.

In the *Zeppelin* airship a light aluminium alloy, said to be wolframium, is used for the framing. The girders, both longitudinal and transverse, are either of triangular or trapezoidal section about 7 to 8 inches deep. In the triangular section, an angle section is fitted at each corner, and these are connected together by bracings of stamped section inclined at 45°, and connected by two rivets at each end. In the trapezoidal section the shorter of the parallel sides is a channel section, angle sections being fitted at the extremities of the longer parallel side. The channel and the angles are connected together by stamped braces as already described. The apex member of the keel is either a tube or a rectangular girder, which is connected to the two lower main longitudinal frames of the airship by circular struts about 8 or 10 feet apart. Wire bracing is fitted in the panels formed by the apex girder, longitudinal frames, and struts.

In the *Schutte-Lanz* airship the material of the framing is said to be white Russian fir, which is moulded and pressed into channel and angle sections. The frames in the first airship of this type were worked diagonally instead of transversely and fore and aft as in the Zeppelin. In a later design just completed it is understood they are worked transversely and fore and aft.

In the *Speiss* (French) airship the main framing is of wood and the transverse and longitudinal frames are worked very similar to the Zeppelin design, i.e. the transverse frames in short lengths forming the sides of the polygon, and the longitudinals running fore and aft between transverse frames, and connected to them at the corners of the polygon. The portions of the framing are tapered, the sectional area being largest in the middle and smallest at the ends or joints.

The wire bracing in the Zeppelin is of high strength steel, and it is understood this material is also used in the Schutte-Lanz and Speiss rigid airships.

In the British Naval airship, built by Messrs. Vickers some years ago, *duralumin*, a light aluminium alloy, was employed. This has a tensile strength of about 25-30 tons, yield-point 22 tons, extension 10-18 per cent, a modulus of elasticity of about $10{\cdot}5 \times 10^6$ lb. units, and a specific gravity of about 2·8.

Steel has been proposed as the material for the framing of rigid airships. The modulus is 30×10^6 and, although for equal weight to aluminium alloys, the products of modulus and inertia for the same shape of girder are the same, thus ensuring equal resistance against buckling, yet the extreme thinness required for the steel framing must result in great difficulties in construction. An aluminium alloy of moderate tensile strength, easily worked into the necessary construction sections, capable of withstanding atmospheric conditions without deterioration, appears to be the most suitable material, since the modulus of most of these alloys is in the neighbourhood of $10{\cdot}5 \times 10^6$ lb. inch units, and their specific gravity between 2·7 and 2·8.

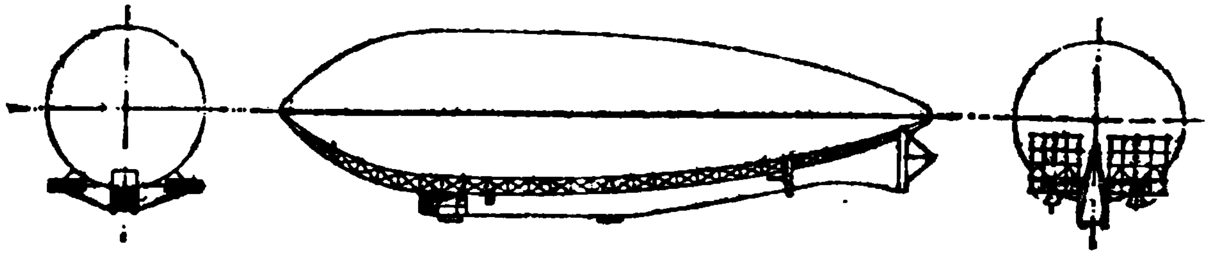
Stabilizing Planes, Rudders, etc.

Experiments carried out at the National Physical and also at the Göttingen Laboratories show that for airship forms the resultant force when the airship is inclined slightly to the direction of the resultant wind will act at some considerable distance forward of the centre of gravity, and thus tend to further increase the inclination, i.e. the model is unstable. In the cases tried the line of action of the resultant force at small angles was far forward of the nose of the ship. The addition of plane fins placed at the tail of the model had a very marked effect on the line of action of the resultant force, the effect being greater as the area of the fins was increased, and after a certain area was exceeded the line of action of the resultant force passed aft of the centre of gravity, and thus tended to diminish the inclination, i.e. it rendered the ship stable. Stabilizing planes are therefore fitted in nearly all airships, and since motion takes place in any direction, both vertical and horizontal fins are necessary. In the latest Zeppelin airships the shape of the fins in profile or plan is practically that of a rectangle of the same height or breadth as the maximum diameter of the ship, and finishing at the after extremity. In some of the French and British airships four or more external ballonets of spindle shape have been fitted at the after end to act as stabilizers. In the *Parseval* airships vertical and horizontal fins are fitted at about a quarter the length of the ship from the after end.

The steering and elevating rudders in the latest airships are placed at the stern on each side, and are balanced and of the box type actuated by a curved sector and wires from the car or cars. In some cases elevating planes are fitted forward as well as aft, and this was the case in the earlier Zeppelins. In the *Forlanini* elevating rudders are fitted just forward of amidships and also aft at the tail. In

some cases also the rudders and elevating planes are of the flexing type, i.e. the fore edges are fixed and the trailing edges are pulled one way or other

FIG. 237.



In the Forlanini airship (fig. 237), 236 feet long and 59 feet diameter, the area of the rudder is 409 square feet, the stern elevating planes are 323 square feet, and the forward ones 215 square feet. In a Zeppelin airship, 490 feet long and 40 feet diameter, the rudders have an area of 330 square feet and the elevating planes 400 square feet. In a Parseval, 190 feet by 30 feet, the rudder is 80 square feet, carried at the after end of a stabilizing fin of 200 square feet. The horizontal stabilizing planes have an area of 340 square feet. No elevating planes are fitted, the vertical steering being obtained by pumping air from one ballonet to the other or by longitudinal shift of weight. In a later Parseval a central ballonet only is fitted and elevating planes are fitted towards the fore end.

There is very little information as to the steering capabilities of airships. That published for the Zeppelin *Schwaben* is as follows :—

Condition.	Time of turning.	Speed of ship.	Diameter of circle in lengths of ship.
	secs.	m.p.s.	
3 motors, rudder hard-a-port	133	15	4¼
2 " " "	134	12·4	3·8
Starboard motor, starboard turn	265	9·6	5·8

LIFTING POWER.

At 0° C. and 760 mm. pressure, 1,000 cubic feet of air weigh 80·7 lb. At the same temperature and pressure 1,000 cubic feet of chemically pure hydrogen weigh 5·7 lb., giving a lifting power of 75 lb. per 1,000 cubic feet. Commercial hydrogen is not pure, and under the same conditions 1,000 cubic feet will lift about 74 lb. According to Pietsker (German I.N.A.), in practice 1,000 cubic feet of hydrogen will lift about 72·7 lb., whilst if the fabric is not of the best material this is reduced to 69 lb. For continuous running the same authority gives 70·6 lb. per 1,000 cubic feet, which at 15° C. and 760 mm. reduces to 69 lb. The usual figure taken

is 1,000 cubic feet of gas-bag capacity lifts 68 to 70 lb. A rise of temperature of 1° C. reduces the lifting power by ·37 per cent. Increase in altitude diminishes the density of the air and the theoretical lifting power diminishes as shown below :—

	Lifting power per 1,000 cubic feet. lb.
At sea-level at 0° and 760 mm. . .	70
1,000 feet high	67½
2,000 „ „	65·1
3,000 „ „	62·8
4,000 „ „	60·5
5,000 „ „	58·5
6,000 „ „	56·3
10,000 „ „	48·7

Actually the lifting power is also affected by other circumstances, since it generally happens that due to radiation the hydrogen is at a higher temperature than the air. In Zeppelin airships this difference has been measured and sometimes amounts to 11° C. Taking the above figures it will be seen that the lifting power of an airship of capacity 640,000 cubic feet which is 20 tons at sea-level is at 5,000 feet altitude only 16·7 tons, and thus 3·3 tons of disposable weight must be got rid of to allow the airship to attain and remain at that height. Since at this height the volume of the hydrogen is increased by about 16 per cent the valves must be of such a size that the gas can escape whilst the ship is attaining the height.

According to Pietsker, rain or snow will increase the weight of a Zeppelin by 1 to 1½ tons, whilst a very damp atmosphere may increase it by about 1,300 lb.

The net lifting power, i.e. the lift exclusive of the fixed weight of ship (hull structure, envelopes, engines, rudders, fittings, etc.) which can be utilized for the carriage of fuel, ballast, crew, stores, armament, wireless gear, etc., varies in different designs and must necessarily depend on the speed, since this determines the weight of the engines. In the Forlanini semi-rigid *City of Milan* it is 32 per cent of the gross lift. In a passenger-carrying Zeppelin it is 25 per cent. In a Zeppelin for war service it is stated to be 28 per cent, whilst in the Parseval design it is from 29 to 33 per cent.

The loss of hydrogen by permeation through the fabric of the envelope will be always diminishing the total lifting power, and therefore also the net lift. Thus, taking an airship with a surface of 24,000 square feet and with a fabric whose permeability is 10 litres per square metre in twenty-four hours, the loss of hydrogen by permeation is 800 cubic feet in twenty-four hours. This represents about ·6 per cent of the total gas capacity of the envelope whose surface has been taken.

Resistance of Airships.

There is little information available as to the resistance of airships. The results of trials on two—the *La France* of Renard and the Zeppelin *Schwaben*—have been published. The former, one of the earliest dirigibles, was 50·4 m. long, 8·4 m. diameter, and 1,864 cubic metres capacity. A Gramme motor of 9 nominal H.P. gave a speed of 6·5 m.p.s. A two-bladed tractor screw was used.

If R is the resistance in lb., A the area of the largest cross-section, V the velocity in miles per hour, and K the coefficient of resistance, and $R = KAV^2$, in the case of *La France*.

$$K = \text{propulsive coefficient} \times \cdot 0014.$$

Taking the propulsive coefficient as 40 per cent.

$$K = \cdot 00056 \text{ or } R = \cdot 00056AV^2.$$

Schwaben.—In the case of the *Schwaben* the trials were more extensive, and the following results were obtained :—

Date.	Total Power.	Speed.	Propulsive Coefficient.
		m.p.s.	
29-6-11	454	19·6	·55
„	290	16·8	·55
8-7-11	288	16·4	·55
„	136	11·4	·38
15-7-11	454	19·34	·55
„	290	16·63	·55
„	136	11·30	·38

The propulsive coefficients were deduced from trials on the motors and propellers. The published dimensions of the *Schwaben* are 459 feet long, 46 feet diameter, and 629,000 cubic feet capacity. From the above results the resistance (R) in the same units as before is given by $R = \cdot 00070\, AV^2$. This result was confirmed by stopping tests in which the motors were stopped and the decrease of speed over measured times observed.

Model Experiments.

Experiments on models have been carried out by O'Gorman at the Royal Aircraft Factory and by Prandtl at Gottingen.

The former used model balloons of goldbeater's skin, the models being towed at speeds of from 10 to 25 f.p.s. The table on p. 439 shows the results.

Little information is given as to the method of the experiments, but the value of the coefficient for a circular plane 3 feet diameter, obtained by the same method, is 14 per cent greater than that given by Eiffel, and 16 per cent greater than that given by Stanton.

Model.	Length in feet.	Diameter in feet.	Volume in cubic feet.	Prismatic coefficient.	Surface in square feet.	Resistance in lb. at 20 f.p.s.
N.P.L. (12) .	$19\frac{1}{2}$	$3\frac{1}{48}$	90·5	·66	141·4	·380
Clement-Bayard	18	$3\frac{5}{48}$	88·5	·69	137·4	·388
Beta . .	$13\frac{1}{4}$	$3\frac{1}{6}$	62·3	·60	102·6	·340
Gamma . .	$16\frac{1}{12}$	$3\frac{1}{8}$	78·4	·64	122·9	·380
B.F. (36) . .	$17\frac{1}{4}$	$2\frac{23}{24}$	75·4	·62	121·8	·342
Lebaudy . .	$17\frac{5}{12}$	$2\frac{1}{24}$	45·2	·71	96·0	·229
Mayfly . .	17	$1\frac{5}{8}$	28·2	·80	76·5	·173
B.F. (32) . .	$18\frac{5}{8}$	$3\frac{1}{12}$	94·0	·67	143·0	·377

The total resistance was found to vary as the 1·98 power of the speed. Expressing the resistance as before in terms of the area of greatest cross section the coefficient of total resistance (K_T) is given below. If the frictional resistance is calculated by Zahm's formula and subtracted from the total, the *head* or *form resistance* is obtained. The value of K_H the coefficient for this resistance is also given.

Name of model.	Value of K_T, the total resistance coefficient.	Value of K_F or skin resistance coefficient.	Value of K_H, the head or form resistance coefficient.
N.P.L. 12 . .	·000285 at 20 f.p.s.	·000125	·000160
Clement-Bayard	·000275 at 20 „	·000150	·000125
Beta . . .	·000245 at 25 „ ·000251 at 10 „	·000109	·000136
Gamma . . .	·000267 at 25 „ ·000275 at 10 „	·000126	·000141
B.F. 36 . . .	·000267 at 25 „ ·000274 at 10 „	·000148	·000119
Lebaudy . .	·000376 at 20 „	·000246	·000130
Mayfly . . .	·000448 at 25 „ ·000466 at 10 „	·000315	·000133
B.F. 32 . . .	·00027 at 20 „	·000126	·000144

These results show that the head or form resistance varies in the different models from 30 to 55 per cent of the total, the smaller percentage being for the ship having the largest $\frac{\text{length}}{\text{diameter}}$ ratio, the *Mayfly*. For the next smaller ratio—*Lebaudy*—the percentage is about 35. For the full-sized naked models the head or form resistance will be a larger percentage of the total resistance, since the skin friction becomes relatively less. For a naked full-sized *Mayfly* the percentage is increased to 35 per cent.

GÖTTINGEN RESULTS.

The models employed by Prandtl were of thin metal with copper deposited surfaces. They were surfaces of revolution and stream line form placed in an air current whose speed varied from 2 to 9·8 metres per second. The total resistance was first measured. Afterwards small holes were pierced along a meridian line on the model, and these holes were in turn unplugged, the pressure in the interior measured and taken as being the pressure on the surface at the point considered. These pressures were resolved fore and aft and gave the *form* resistance. The difference between the total and form resistance gave the frictional resistance.

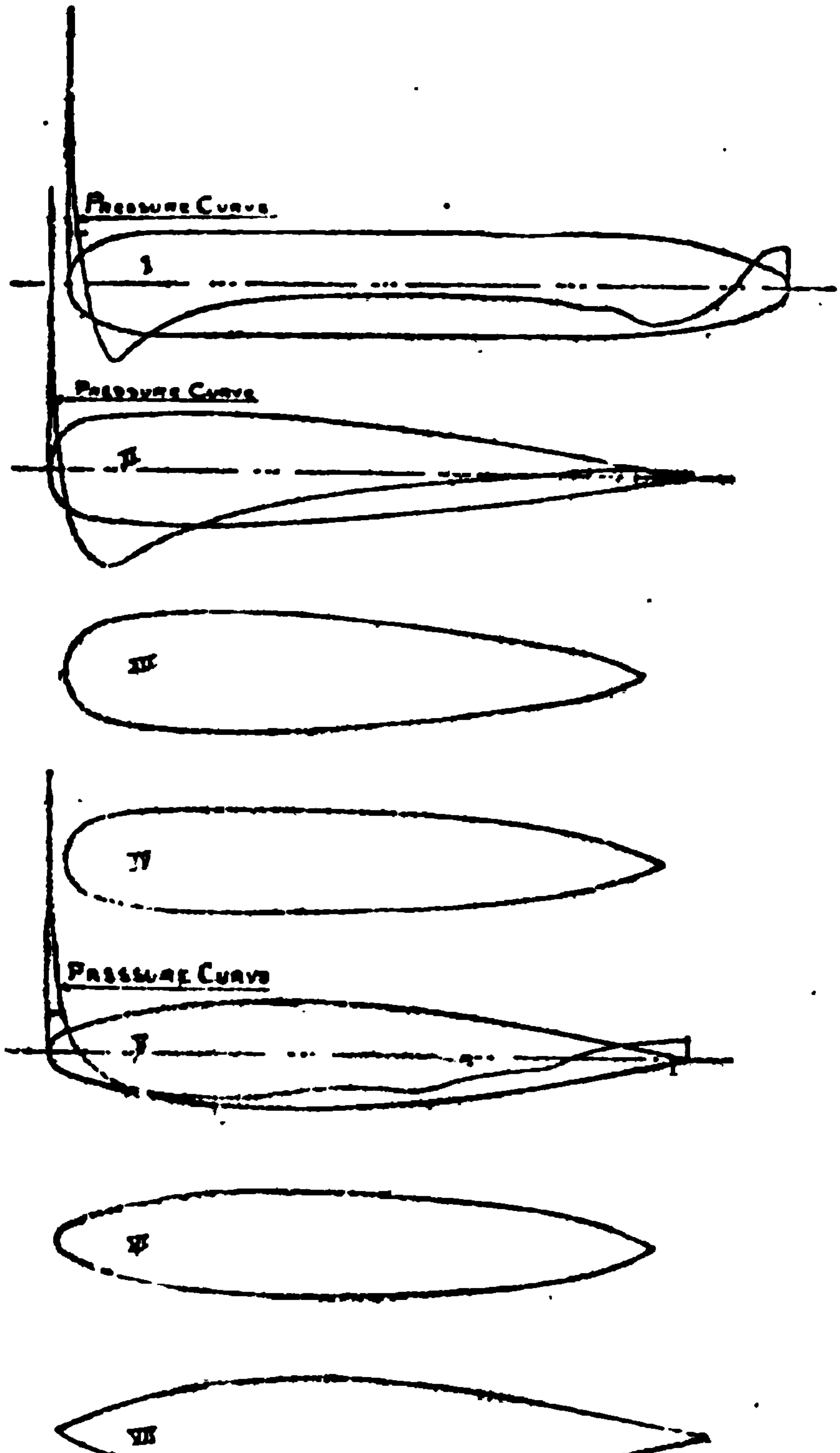
Model.	Length mm.	Diameter, mm.	Volume, cubic m.	Surface, square m.	Prismatic coefficient.	K_T at maximum speed.	K_H	K_F
I	1300	200	·0330	·745	·83	·00030 (·00043)	·000147	·000164
II	1125	194	·0182	·479	·55	·000195 (·00020)	·000113	·000082
III	1032	200	·0182	·479	·56	·00022 (·00026)	·000116	·000104
IV	1062	188	·0182	·479	·61	·00024 (·00027)	·000134	·000106
V	1145	188	·0182	·479	·57	·00016 (·00022)	·00010	·00006
VI	1056	188	·0182	·479	·62	·00018 (·00023)	·000106	·000074
VII	1160	200	·0182	·479	·50	·00015 (·00020)	·0001	·00005

The coefficients K_T, K_H, and K_F are the coefficients giving the resistances in pounds in terms of the maximum area in square feet and miles per hour, K_T being the total, K_H the head or form, and K_F the skin friction resistance. The values of K_T given in brackets are for the lowest speeds. The *form* or *head* resistance at the maximum speed varies in the different models from 47 to 66 per cent of the total, which is greater than the O'Gorman results. It has been stated that the skin resistance for polished copper surfaces is about one-half that for balloon fabrics. This is hardly in agreement with Zahm's results, which gave the same results for all smooth surfaces. If such a difference exists this may account for the relatively larger percentages of the form resistance as compared with the O'Gorman results.

Compared with the results for skin resistance as calculated by Zahm's formula, the experimental results are very much

smaller and vary with different powers of the speed. The power of the speed with which the frictional resistance varies is 1·81, 1·74, 1·78, 1·81, 1·49, 1·54, and 1·48 in the seven models. Fuhrmann, however, points out that small errors in the pressures measured involve large differences in the frictional resistance deduced.

FIG. 238.



The models are shown in fig. 238 and in three of these the curves of pressure are shown, the base-line of these curves being the axes of the models. Ordinates below the

axis represent defect pressures and those above excess pressures. The pressure at the extreme forward end was in all cases found to be that equivalent to the head due to the speed.

Other experimental results which have a slight bearing on airship resistance are given below :—

Authority.	Shape of model.		Value of K_T.	
Eiffel	Cylinder with hemispherical ends, 90″ × 6″		·00049	
,,	Cone with vertical angle 20° with hemisphere (4″ rad. on base)	at 12 m.p.h.	·00037	base first.
		at 36 m.p.h.	·00026	base first.
			·00022	apex first.
Renard	Surface formed by revolving parabolic curve (L = 2B)		·00022	
,,	Surface formed by revolving parabolic curve (L = 3B)		·00011	
,,	Fusiform body (L = 2B)		·00013	

Comparison of Model and Full-sized Results.

The exact law connecting the resistance of the full-sized airship with its model is not yet fully understood. Theoretically the law connecting speeds and dimensions gives LV = a constant for airship and model, and this law would necessitate the corresponding model speed being very much greater than the airship speed, an impracticable condition. Moreover, it would appear that as the speed of model increases, the coefficient of resistance (assuming the V^2 law to apply) diminishes. If the LV law of comparison is the true one, the coefficients of resistance for the model taken in the following comparison are therefore too large when applied to the full-sized ship. In any case the comparisons given below can only be taken as very rough approximations.

Taking the O'Gorman *Mayfly* model as representative of the Zeppelin airships, and the head resistance coefficient ·000133 to be the same in the model and full-sized ship, but the frictional coefficient to vary with length in accordance with Zahm's formula, the total resistance of a full-sized Zeppelin = $\cdot000383AV^2$ compared with $\cdot000448AV^2$ for the model.

If this is compared with the experimental result on the *Schwaben* $R = \cdot00070AV^2$ it must follow that the difference $\cdot00032AV^2$ must be due to the resistance of the appendages, i.e. to the car, keel, struts to propeller, etc., all of which were absent in the model. That is the model results modified for

the difference in skin friction must be increased by 80 per cent to give the total resistance of the actual airship. Taking the propulsive coefficient as 50 per cent one arrives at the result that the indicated resistance of airship $= 2 \times 1{\cdot}8 \times {\cdot}000383\text{AV}^2 = {\cdot}00136\text{AV}^2$, which agrees fairly well with the results obtained by comparison of the H.P., estimated speed and dimensions as published for Zeppelin airships.

Model IV of the Gottingen experiments is practically the same form as *Parseval* airships.

The total resistance for Model IV $= {\cdot}00024\text{AV}^2$. If this is multiplied by 3·6 as for the Zeppelin, one arrives at the indicated resistance $= {\cdot}00086\text{AV}^2$, which compares with ${\cdot}0009\text{AV}^2$ deduced from the H.P., estimated speed, and dimensions of the latest Parseval designs. No deduction has been made for the difference in frictional or skin resistance. This should amount to about 50 per cent of the coefficient of the latter in the model, but as already pointed out the skin resistance of the polished copper models is stated to be much less than that of balloon fabrics, and the increase due to this would probably counterbalance the decrease due to difference in lengths.

The *Forlanini* airship is very similar to O'Gorman's model *Beta.* The total resistance of the latter when modified for decreased skin coefficient due to length becomes $= {\cdot}00022\text{AV}^2$ as compared with an actual indicated resistance $= {\cdot}00036\text{AV}^2$. The propulsive coefficient must be very high, and the appendage resistance very small, therefore, to obtain agreement since the model resistance is only 60 per cent of the indicated resistance. Possibly the published H.P. is understated.

Published dimensions and speeds of the *Beta* airship give an indicated resistance $= {\cdot}00082\text{AV}^2$, which is just 3·5 times the model resistance modified for the difference in skin friction coefficient due to difference in length. In the case of *Gamma* a similar comparison gives 3·3 as the ratio.

From the above figures it would therefore appear that the indicated resistance, i.e. the resistance as deduced from I.H.P., is roughly given by taking the nearest model results, modifying the portion due to skin friction for the difference in lengths by Zahm's formula and multiplying the result by 3·6, or if model results are not available the indicated resistance for a *Zeppelin* ship is given by

$$\text{R} = {\cdot}00136\text{AV}^2.$$

This value would also appear to apply fairly well to airships whose fineness, ratio, i.e. $\dfrac{\text{length}}{\text{diameter}}$, is great, i.e. the *Speiss, Siemens-Schukert,* and *Schutte-Lanz* airships.

For the non-rigids and semi-rigids, whose ratio of length to diameter varies from 4 to 6, the indicated resistance is approximately given by $R = \cdot0008$ to $\cdot001AV^2$.

The figures which have been given showing the difference between the naked model results and those of the actual airships show the large effect of the resistance due to wires, struts, cars, etc. It is, therefore, important for best speed results to make this as small as practicable. In the *Astra-Torres* airship the section is trilobular, and the wiring is placed inside the envelope. The junctions of the lobes are fitted with longitudinal wires connected across by vertical wires. This to a great extent accounts for the good speed results obtained in this design.

Subsequent to the writing of these notes *Eiffel* has published in *Nouvelles recherches de la résistance de l'air et l'aviation* results of experiments on models of three dirigibles, viz.: (1) the *Clement-Bayard*, (2) the *Fleurus*, and (3) the *Astra-Torres*. The models were of polished wood and were tried bare and also fully equipped. The lengths varied from 1 to 1½ metres and the speed of experiment from 8 to 25 metres per second. For this range of speed the resistance varied as the square of the speed.

Expressing the resistance as before in terms of the maximum cross-sectional area the values of the coefficient of resistance for bare hulls in British units are :—

Clement-Bayard	$K = \cdot000296$
Fleurus	$K = \cdot000198$
Astra-Torres	$K = \cdot00024$

The first compares with $K = \cdot000275$ determined by O'Gorman for a much longer model of the same design.

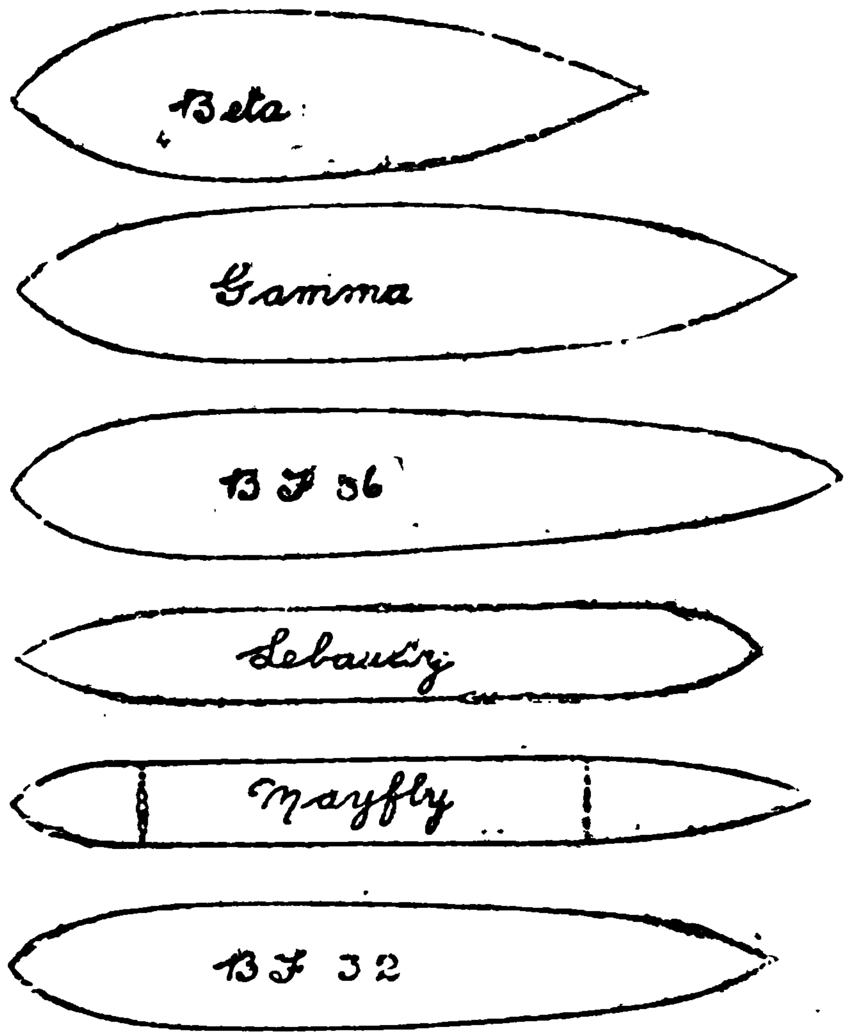
For the fully equipped models the values became ·00067, ·00073, and ·00072 respectively, but it is quite probable these values are excessive since the reproduction to accurate scale of the ropes and other small fittings in the models is very difficult. In the case of the *Astra-Torres* it was found that the rudder, elevating planes, and fliers were alone responsible for a coefficient of resistance equal to ·00018.

Form given to Airships.

The form of the envelope in various designs of airships are shown in the figure. In the rigid type a fairly long parallel middle body amounting to from 50 to 60 per cent of the overall length is allowed. Before and abaft this the form is tapered, the radius of the head varying from 1½ to 2 diameters of the ship, and the radius of the tail from 7 to 9 diameters.

For non- and semi-rigids there is no or very little parallel body except in the Lebaudy design, the head is struck to a radius of 1 to 2 diameters of the ship, and the tail to a radius of 5 to 7 diameters.

FIG. 239.



MATERIALS OF THE ENVELOPES.

The material to be used for the envelopes of airships must be light, strong, impervious to hydrogen and moisture, and fairly durable. The material is usually rubbered cotton, i.e. fine cotton material in one, two, or three layers with a thin coating of rubber on the inside and between the layers. In some small airships gold-beater's skin, an animal tissue obtained from the large intestines of the ox, has been employed. This material is costly, but from the point of view of permeability is the best.

So far as the rubbered cotton fabrics are concerned the double thickness is usually arranged with the threads parallel, but in some cases the threads are crossed diagonally. The material is manufactured in rolls about 100 yards long and 3 to 4 feet wide. The edges of adjacent lengths are lapped,

stuck together with rubber insertion, the lap double-stitched through, and a rubbered cotton tape stuck on over the lap both inside and out.

The following is taken from the report of tests on balloon fabrics by the National Physical Laboratory:—

Fabric.	Weight in lb. per sq. yd.	Tensile Strength, lb. per ft. width.		Permeability, cubic ft. per sq. ft. per 24 hours.
		Warp.	Weft.	
Single rubbered fabric . .	·417	488	515	·0415
Double fabric, one layer rubber	·499	1008	732	·0442
Parallel double, two ,, ,,	·417	—	—	·0436
,, ,, ,, ,, ,,	·444	637	620	·0282
,, ,, ,, ,, ,,	·433	708	731	·0302
,, ,, (coloured yellow)	·612	1030	768	·0357
,, ,, three layers rubber	·599	913	—	·0380
Diagonally ,, two ,, ,,	·407	697	752	·0240
,, ,, three ,, ,, (Red rubber outside.)	·604	456	384	·0138
Treble fabric	·582	1548	1476	·0424
Goldbeater's skin, four layers .	·168	—	—	·0009
,, ,, five ,, .	·204	—	—	·0013
,, ,, eight ,, .	·554	—	—	·0003

Exposure to the weather for fifty days reduced the strength by about 20 to 30 per cent, and increased the permeability considerably.

The following table shows the material of the envelopes stated to be used in various designs of airships:—

Makers of Airships.	Weight in lb. per sq. yd.	Type of Fabric.	Tensile Strength, lb. per ft. width.	Cotton, lb. per sq. yd.	Rubber, lb. per sq. yd.
				2 layers each.	
Lebaudy, Astra, Italian	·608	Double parallel	1008	·159	·290
Astra and Clement	·700	,, ,,	1340	·205	·290
Parseval .	·728	,, diagonal	806	·205	·318
Zeppelin .	·478	,, parallel	605	·094	·290

The French Government Specification for fabric requires two thicknesses of cotton each 86 grammes per square metre, to be worked warp on warp and weft on weft. Outside thickness coloured yellow with lead chromate. Between the two is worked a layer of rubber weighing 83 grammes per square metre. This layer of rubber consists of two separate layers, one unvulcanized (50 grammes per square metre) next outer thickness of cotton and the other vulcanized and weighing 33 grammes per square metre. On the inside of inner thickness of cotton a layer of vulcanized rubber 75 grammes per square metre is worked. Total weight 330 grammes per square metre (·608 lb. per square yard). Limits allowed 320 to 340. Rubber to be pure Para vulcanized under heat; 5 to 7 per cent sulphur, no other mineral. Tensile strength 1,500 kilos. per metre width (1,008 lb. per foot width) in warp or weft; limit 1,350 kilos. Permeability to be less than 10 litres per square metre (·033 cubic feet per square foot) in twenty-four hours. Another account gives the construction cotton layer coloured with lead chromate 85 grammes, unvulcanized Para rubber 45 grammes, vulcanized rubber 40 grammes, cotton layer 85, Para rubber vulcanized 75. The German fabric is stated to be cotton layer coloured with aniline 110 grammes, Para vulcanized 130 grammes, cotton layer 110 grammes, Para vulcanized 30 grammes.

In some airships the upper portion of the envelope has been covered with aluminium powder to reflect the rays of the sun. In the latest Zeppelins it is stated that the gas-bags are of single cotton rubbered on the inside, and lined with goldbeater's skin to decrease the permeability.

Tensions in the Envelope of a Non-rigid Airship.

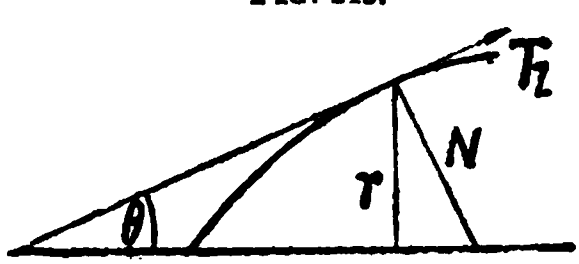
The longitudinal and transverse tensions in the fabric are connected with the pressure p by the relation :—

$$\frac{T_l}{R_l} + \frac{T_t}{R_t} = p,$$

where R_l and R_t are the principal radii of curvature at the point considered.

T_l is obtained from consideration of the equilibrium of the portion of the airship cut off by a transverse plane through the

FIG. 240.



point. Resolving along the axis the resultant tensile force around the circumference must equal the whole pressure on the section in the direction of the axis, or $2\pi r \,.\, T_1 \cos\theta = \pi r^2 \,.\, p$. Now $\cos\theta = \frac{r}{N}$ where N = length of normal intercepted between curve and axis; hence $T_1 = \frac{Np}{2}$ and $N = R_1$; hence $T_t = Np\left[1 - \frac{N}{2R_1}\right]$.

$T_t = 0$ when $N = 0$, which is the case at the extremities, and $= Np$ when $R_1 = \infty$, which is the case when the curve is a straight line, i.e. where there is a parallel portion. At the maximum diameter $N = \frac{D}{2}$, where D is the diameter, and the value of T_t becomes $= \frac{pD}{2}\left[1 - \frac{D}{4R_1}\right]$ and $T_1 = \frac{pD}{4}$, showing that the tensions increase with the diameter if the pressure p remains constant.

For the airship to maintain its shape under a bending moment M (taken for comparison at the greatest diameter D) there must be no compressive stress on the fabric. This condition is satisfied when $M = \frac{\pi p D^3}{16}$, or since in similar ships M should vary as D/p, the excess pressure p should vary as D and the tensions in the material will thus vary as D^2. In the above the bending moment has been considered. If the shearing force on a section due to vertical loading is considered, this shearing force is equivalent to compressive and tensile forces acting in a direction at 45° to the vertical. So long as the equivalent compressive force is less than the tension on the fabric the airship will retain its form. This condition is less difficult to satisfy than that due to the bending moment.

BOARD OF TRADE REGULATIONS FOR MARINE BOILERS, Etc., IN PASSENGER STEAMSHIPS.

Hydraulic Test.

All new boilers to be tested hydraulically, previously to their being placed in the vessel, to double the working pressure. Old boilers to be tested to $1\frac{1}{2}$ times the pressure after important repairs.

Test Pieces for Materials.

For plates and sectional bars to be about 18″ long, of which at least 9″ to be planed down parallel to take gauge marks 8″ apart; the width of this portion to be $1\frac{1}{2}$″ if over $\frac{7}{8}$″ thick, 2″ from $\frac{3}{8}$″ to $\frac{7}{8}$″, $2\frac{1}{2}$″ under $\frac{3}{8}$″. (Designation A.)

For round bars, rods, and stays to have enlarged ends separated by a parallel portion of length not less than 9 diameters, to take 8-diameter gauge marks. (Designation B.) Alternately, bars over 1″ diameter may have 4½ diameters parallel length to take 4-diameter gauge marks. (Designation F.)

For forgings and castings to be circular (the ends being enlarged), with dimensions as follows:—

Designation.	Diam. of parallel portion in in.	Area in sq. in.	Parallel Length, in.	Gauge length, in.
C	·564	¼	2¼	2
D	·798	½	3⅜	3
E	·977	¾	4	3½

For bending tests, pieces from plates or sections should be at least 1½″ wide; from round bars should be of full section (those more than 2″ diameter may be turned down to 2″); from forgings and castings to be rectangular 1″ × ⅝″, machined, with corners rounded to $\frac{1}{16}$″ radius, to be bent over the smaller section.

Tests for Materials.

Those regarding boiler material refer to ordinary mild steel. In all cases the test pieces and gauge lengths described above are assumed.

Plates (ordinary).—Tensile, 27 to 32 tons per square inch; elongation, 20% above ⅜″ thick, with reduction of 3% for each ⅛″ less than ⅜″. Bending through 180° with inner diameter three times the thickness.

Plates (to be worked in fire or exposed to flame).—Tensile, 26 to 30 tons per square inch; elongation, 23%, with reduction as above. Bending, as above, but with tempered strips.

Stays, Angle, and Tee Bars.—Tensile, 27 to 32 tons per square inch; elongation, 20%, except for combustion chamber stays, where test is 26 to 32 tons per square inch, with elongation 23%. On test piece F the elongations should be 24% and 28% respectively. For sectional bars under ⅜″ thickness deduct 3% from elongation allowed for plates. Bending tests as for plates.

Rivet Bars.—Tensile, 26 to 30 tons per square inch, with elongation 25% on B or 30% on F.

Rivets.—Shanks bent cold, and hammered right over to 180° without fracture. Heads to be flattened, when hot, until diameter is 2½ times that of shank, without cracking at edges. Tensile (on length 2½ times diameter), 27 to 32 tons per square inch; contraction of area about 60%.

Solid-drawn Steel Steam Pipes, Boiler Tubes, etc., subject to internal pressure.—Tensile, 23 to 30 tons per square inch, with elongation 20% in 8″, or 18% if thickness is less than ¼″. All tubes to be tested to a suitable hydraulic pressure.

Solid-drawn Steel Tubes, subject to external pressure.—Tensile, 23 to 30 tons per square inch, with elongation as above. Hydraulic test.

Steel Lap-welded Tubes, subject to external pressure.—Tensile (on strips from which tubes are made), 23 to 30 tons per square inch; with elongation 20% in 8″. Hydraulic test.

If no allowance over iron is required the test for the two last may be omitted.

All Tubes.—The hydraulic test should not exceed 3 times the working pressure, or 4 times that given by

$$\frac{6{,}000 \times \text{thickness in inches}}{\text{inside diameter in inches}} = \text{pressure}$$

for lap-welded tubes, or 5 times that pressure for solid-drawn steel tubes. Steel to be open-hearth acid steel. Solid-drawn tubes whose thickness is more than $\frac{1}{8}$″ should be finished by the hot-drawn process.

Forgings.—Tensile, not exceeding 40 tons per square inch; with elongation 17%; for lower tensile strengths the sum of this and of the elongation percentage should not exceed 57. Bending, through 180° with internal radius $\frac{1}{4}$″ up to 32 tons per square inch, $\frac{3}{8}$″ from 32 to 36, and $\frac{5}{8}$″ from 36 to 40.

Castings.—Tensile, 26 to 40 tons per square inch; with elongation 15%. For pistons and important parts elongation should be 20% if tensile strength is less than 35 tons per square inch. Bending, if tensile 35 to 40, through 60°; otherwise through 90°; for important parts through 120°; internal radius of bend 1 inch. All steel castings to be annealed.

The above tests for steel castings may be omitted if the scantlings be those appropriate to cast iron.

Steel Boilers.

Plates used to be not less than $\frac{5}{16}$″ thick. Rivet holes to be drilled. Plates drilled in place to be taken apart and the burr taken off, and the holes slightly countersunk from outside. After local heating plates should be annealed. When the cylindrical shells of boilers are of material, tested and approved, with all the rivet holes drilled in place, and all the seams fitted with double butt-straps, each of $\frac{5}{8}$ the thickness of the plates they cover, and all the seams at least double-riveted with rivets having an allowance of not more than $87\frac{1}{2}$ per cent over the single shear, provided that the boilers have been open to inspection during the whole period of construction, then 4·5 may be used as the factor of safety, the minimum actual tensile strength of the plates being used in calculating the working pressure.

TABLE GIVING THE CONSTANTS TO BE ADDED TO THE FACTOR OF SAFETY FOR CYLINDRICAL BOILERS.

Mark	Constants	Circumstances in which the constants have to be added.
A	·15	When the holes are fair and good in the longitudinal seams, but drilled out of place after bending.
B	·3	When the holes are fair and good in the longitudinal seams, but drilled out of place before bending.
C	·2	When double butt-straps are not fitted to the longitudinal seams, and said seams are lap and double-riveted.
D	·1	When double butt-straps are not fitted to the longitudinal seams, and the said seams are lap and treble-riveted.
E	·3	When only single butt-straps are fitted to the longitudinal seams, and the said seams are double-riveted.
F	·15	When only single butt-straps are fitted to the longitudinal seams, and the said seams are treble-riveted.
G	1·0	When any description of joint in the longitudinal seams is single-riveted.
H*	·4	When there are two or more belts of plates, and the seams are not properly crossed.
I	·1	When the holes are fair and good in the circumferential seams, but drilled out of place after bending.
J	·15	When the holes are fair and good in the circumferential seams, but drilled before bending.
K	·1	When the circumferential seams are fitted with single butt-straps and are double-riveted.
L	2	When the circumferential seams are fitted with single butt-straps and are single-riveted.
M	·1	When the circumferential seams are fitted with double butt-straps and are single-riveted.
N	1	When the circumferential seams are lap joints and are double-riveted.
O	2	When the circumferential seams are lap joints and are single-riveted.
P	·3	When the boiler is of such a length as to fire from both ends, or is of unusual length, such as flue boilers, and the seams are fitted as described opposite K, M, and N; but when the circumferential seams are as described opposite L or O, P ·3 will become P ·4.

* The allowance may be increased still further if the workmanship or material is very doubtful or very unsatisfactory.

When the above conditions have not been complied with, the additions in the scale (p. 451) should be made to the factor of safety, according to the circumstances of each case.

Strength of Joints and Pressure on Safety Valves in Cylindrical Boilers.

FORMULA (Inch-ton units).

P = percentage of strength of plate at joint as compared with the solid plate.
P′ = percentage of strength of rivets as compared with the solid plate.
p = pitch of rivets.
a = area of one rivet.
d = diameter of rivets.
n = number of rows of rivets.
S_1 = minimum tensile strength of plates.
S_2 = shearing strength of rivets to be taken as 23.
C = 1 for rivets in single shear = 1·875 for double shear.
t = thickness of plate.

$$P = \frac{(p-d)\times 100}{p} \qquad P' = \frac{(a\times n)\times 100}{p\times t}\times\frac{S_2 C}{S_1}$$

If percentage strength of rivets in longitudinal seams is less than calculated strength of plate, then pressure on shell should be calculated from each percentage

$$= \frac{S_1 \times 2{,}240 \times \%\ \text{strength of joint} \times 2t}{D \times \text{factor of safety} \times 100}$$

where D = inside diameter of boiler. The smaller of the two pressures is that to be allowed; take factor of safety = 4·5 for rivets or as found from the table for the plates.

For steel plates and iron rivets, take $S_2 = 17{\cdot}5$. For iron plates and rivets take $S_2 = S_1$.

Where alternate rivets are omitted in the outer rows

$$P = \frac{100(p-2D)}{p} + \frac{P'}{n}$$ where p is the greatest pitch, i.e. at the outer row.

The diameters of the rivets should not be less than the thickness of the plates.

Rivet Spacing, etc., in Joints.

From the above formulæ the value of any type of joint can be calculated.

In addition let

V = perpendicular distances between rows of rivets.
E = distance from edge of plate or butt-strap of centres of outer row.
t_1 = thickness of butt-strap (supposed of same material as plate).

(*a*) Joints where no rivets are omitted.

$t_1 = \frac{5}{8}t$ for double straps $= \frac{9}{8}t$ for single straps.

$\text{E} = \frac{3d}{2}$, $\text{V} = 2d$* for chain riveting.

$\text{V} = \frac{1}{10}\sqrt{(11p + 4d)(p + 4d)}$ for zigzag riveting.

(*b*) Joints where alternate rivets are omitted from the outer row,* (p = pitch at outer rows : V_1 = distance between adjacant rows both containing the full number of rivets ; V = distance when one row has alternate rivets omitted.)

$$t_1 = \frac{5t(p-d)}{8(p-2d)} \text{ for double straps} = \frac{9t(p-d)}{8(p-2d)} \text{ for single straps.}$$

If, in treble-riveted straps, the alternative rivets are omitted also from the inner rows,

$t_1 = \frac{5}{8}t$ for double straps $= \frac{9}{8}t$ for single straps.

$\text{E} = \frac{3d}{2}$.

V (chain riveting $= 2d$† or $\frac{1}{10}\sqrt{(11p+4d)(p+4d)}$, whichever is greater. $\text{V}_1 = 2d$.†

V (zigzag riveting) =

$$\sqrt{\left(\frac{11}{20}p + d\right)\left(\frac{p}{20} + d\right)}$$

V_1 (zigzag riveting) $= \frac{1}{20}\sqrt{(11p+8d)(p+8d)}$.

Maximum Pitches for Riveted Joints.

In inch units, let t = thickness of plate ; p = maximum pitch of rivets; and C a constant from the following table:—

Number of rows of rivets.	Constants for lap joints.	Constants for double butt strap joints.
1	1·31	1·75
2	2·62	3·50
3	3·47	4·63
4	4·14	5·52
5	—	6·00

Then $p = \text{C}t + 1\frac{5}{8}$.

p should never exceed $10\frac{1}{2}$, and should preferably be rather less than that given above.

* In treble riveted butts either the outer edges of both strap and plates or those of the strap only may have alternate rivets omitted.

† $2d + \frac{1}{8}$ is preferable.

Openings in Shells, Doors, etc.

In cylindrical boilers openings in the shell should have the shorter axis placed longitudinally. Compensating rings of the same effective sectional area as the plates cut out, and of the same thickness, should be fitted around all manholes and openings, and efficient stiffening should be otherwise provided. It is desirably that these rings should be of L or T-bar when round openings on flat surfaces. When alternatively the plate is flanged, D, the depth of flange, should be at least equal to $\sqrt{\text{width of opening} \times \text{thickness of plate}}$. Cast-iron doors are not allowed.

Ends.

Hemispherical ends subjected to internal pressure may be allowed twice the pressure suitable for a cylinder of the same diameter and thickness.

Ends of steam receivers which are dished and flanged hydraulically under one heat need not be stayed if radius of end is no more than diameter of shell and does not exceed 4 feet; the outer radius of flange at root should be at least 3 inches, and steel should be of usual quality, and annealed after flanging. The working pressure allowed without stays should not exceed $\frac{90,000\,\mathrm{T}h}{\mathrm{D}^2}$ where T = end thickness, D = diameter of shell, $h = \mathrm{R} - \sqrt{\mathrm{R}^2 - \frac{\mathrm{D}^2}{4}}$, where R = inner radius of end, all in inches.

If the dished ends require stays, but are sufficient for the pressure when considered as portions of spheres, the stays, if of solid steel, may have a nominal stress of 18,000 lb. per square inch. Otherwise the ends should be stayed as flat surfaces. For iron take 14,000, or 10,000 if welded.

Stays for Flat Surfaces.

Solid steel stays may have a working stress of 9,000 lb. per square inch. Welded stays, except strong tubes welded longitudinally, are not allowed. When the threads of longitudinal stays are finer than six per inch, the depths of the external nuts should be at least $1\frac{1}{4}$ the diameter of stay.

For iron stays, stress allowed is 7,000 lb. per square inch, or 5,000 if welded. In combustion chambers 9,000 is allowed, if iron has a tensile strength of $21\frac{1}{2}$ tons per square inch, with elongation 27 per cent in 8 inches.

To find the area of any diagonal stay, find the area of a direct stay needed to support the surface; multiply this area by the length of the diagonal stay, and divide the product by the length of a line drawn at right angles to the surface supported at the end of the diagonal stay.

Note.—When gusset stays are used their area should be in excess of that found by the above rule.

Steel stay tubes may be allowed a stress of 7,500 lb. per square inch (6,000 for iron), but their net thickness should be at least one-quarter inch.

If no allowance over iron is required, stays and smoke tubes should be made of the sizes required for iron.

Girders for Flat Surfaces.

When the tops of combustion boxes, or other parts of a boiler, are supported by solid rectangular girders, the following formula may be used for finding the working pressure to be allowed on the girders, assuming that they are not subjected to a greater temperature than the ordinary heat of steam, and in the case of combustion chambers that the ends are fitted to the edges of the tube plate and the back plate of the combustion box:—

FORMULA.

P = working pressure.
L = length of girder in feet.
T = thickness of girder in inches.
D = depth of girder in inches.
W = width of combustion box in inches.
p = pitch of supporting stays in inches.
d = distance between the girders from centre to centre in inches.
N = number of supporting stays.

$$C = \frac{N \times 1{,}320}{N+1} \text{ when N is odd.}$$

$$= \frac{(N+1)1{,}320}{N+2} \text{ when N is even.}$$

$$P = \frac{C \times D^2 \times T}{(W-p)\,d \times L}$$

For iron substitute 1,200 for 1,320.

Plates for Flat Surfaces.

The pressure on plates forming flat surfaces may be found by the following formula:—

FORMULA.

W = working pressure.
T = thickness of plate in sixteenths of an inch.
S = surface supported in square inches.
C = constant for steel } according to the following circum-
c = constant for iron } stances:—

C = 240 c = 192	when the plates are not exposed to the impact of heat or flame and the stays are fitted with nuts on both sides of the plates, and doubling strips not less in width than two-thirds the pitch of the stays, and of the thickness of the plates, are securely riveted to the outside of the plates they cover.
C = 210 c = 168	as above, but with washers of diameter equal to two-thirds pitch of stays in lieu of doubling plates.
C = 165 c = 132	as preceding, but with loose washers outside, three times the stay diameter, and two-thirds the plate thickness.
C = 150 c = 120	when the plates are not exposed to the impact of heat or flame and the stays are fitted with nuts on both sides of the plate.
C = 112½ c = 90	when the plates are not exposed to the impact of heat or flame and the stays are fitted with nuts only.
C = 77 c = 70	when the plates are not exposed to the impact of heat or flame and the stays are screwed into the plates and riveted over or expanded.
C = 75 c = 60	when the plates are exposed to the impact of heat or flame and steam in contact with the plates, and the stays fitted with nuts and washers, the latter being at least three times the diameter of the stay and two-thirds the thickness of the plates they cover.
C = 67·5 c = 54	when the plates are exposed to the impact of heat or flame and steam in contact with the plate, and the stays fitted with nuts only.
C = 100 c = 80	when the plates are exposed to the impact of heat or flame with water in contact with the plates, and the stays screwed into the plate and fitted with nuts.
C = 66 c = 60	when the plates are exposed to the impact of heat or flame with water in contact with the plate, and the stays screwed into the plate having the ends riveted over to form a substantial head.
C = 39·6 c = 36	when the plates are exposed to the impact of heat or flame and steam in contact with the plates, with the stays screwed into the plate and having the ends riveted over to form a substantial head.

$$W = \frac{C \text{ or } c \times (T+1)^2}{S-6}$$

If thickness of doubling plate be T_1 in sixteenths of an inch, then with unexposed plates

$$W = \frac{C(\text{or } c)\,(T+1)^2 + C(\text{or } c)\,(T_1+1)^2}{S-6}.$$

In calculating the working pressure of the portion of tube-plates between the boxes of tubes, take $2S = D^2 + d^2$, where D and d are respectively the horizontal and vertical pitches of the stay tubes in inches.

Compressive Stress on Tube Plates.

Let D = least horizontal distance between centres of tubes.
d = inside diameter of ordinary tubes.
T = thickness of tube plates.
W = width of combustion-box between tube plate and back of fire-box, all in inches.

$$\text{Working pressure} = \frac{(D-d)\,T \times 28{,}000\ (22{,}000 \text{ for iron})}{W \times D}$$

Furnaces.

For circular furnaces with longitudinal joints welded or made with single straps double-riveted, or double straps single-riveted,

$$\text{Working pressure} = \frac{99{,}000 \times (\text{plate thickness})^2}{(\text{length in feet} + 1) \times \text{diameter}}$$

$$\text{Working pressure should not exceed } \frac{9{,}900 \times \text{thickness}}{\text{diameter}}$$

The thickness and diameter are in inches. For iron take 90,000 and 9,000. With ordinary lap joint take 82,500; for bevelled joint 88,000; for other joints or inferior workmanship the number in the first formula is varied. For the upright fire-boxes of a donkey boiler deduct 10% from both numbers.

For certain types of corrugated furnaces with plates at least $\frac{5}{16}''$ thick

Working pressure =

$$\frac{14{,}000 \times \text{thickness at the bottom of corrugation}}{\text{outside diameter at bottom of corrugations}} \text{ (inch units).}$$

The pitch of corrugations should not exceed 6″ (Fox) or 8″ (Morrison and Deighton); the depth extreme should be at least 2″.

For ribbed and grooved furnaces D = diameter over plain part; the ribs should be at least $1\frac{5}{16}''$ above the plain parts, the depths of grooves not more than $\frac{3}{4}''$, and the spacing not over 9″.

Iron Boilers.

Cylindrical Shells.—Take tensile strength as 47,000 lb. per square inch, with the grain, and 40,000 lb. across; shearing strength of rivets as the same as the tensile strength of plates; take 5 as the factor of safety subject to the other additions specified for steel. If, however, elongation in 10" is 14% with and 8% across the grain, take 4·5 as factor instead of 5, and use actual minimum tensile strength of plates for calculating the working pressure.

Ordinary Smoke Tubes.—Thickness =

$$\cdot 085 + \frac{\text{working pressure} \times \text{outside diameter}}{9{,}000} \text{ in inch units.}$$

The other differences from steel have been indicated above.

Superheaters.

Iron cylindrical superheaters are to be designed as boilers, but using 30,000 (or 22,400 where the flame impinges nearly perpendicular to the plate) instead of 47,000 as the tensile strength.

For a superheater with a tube subject to external pressure treat by the rules for circular furnaces, but reducing the constants in the ratio 30 to 47.

If it consists of a nest or coil of tubes subject to internal pressure, these should be made of solid-drawn steel; otherwise steel is inadvisable in superheaters.

Superheaters must be fitted with drain-pipes and a safety-valve of statutory size (at least 3 inch diameter).

Evaporators, Feed Heaters.

If of iron or steel construct as for boilers.

If of cast iron least thickness should be $\frac{5}{8}''$, if of gun-metal $\frac{3}{8}''$, the tensile strength being 10 tons per square inch;

T = thickness, D = diameter, S = side, all in inches.

C = 4,000 for cast iron; 6,000 for gun-metal.

C_1 = 24,000 for cast iron; 30,000 for gun-metal.

C_2 = 16,000 for cast iron; 20,000 for gun-metal.

B = working pressure.

For cylindrical shells $B = \dfrac{C\,(T - \frac{1}{8})}{D}$

For circular flat surfaces $B = \dfrac{C_1 T^2}{D^2}$

For square flat surface $B = \dfrac{C_2 T^2}{S^2}$

If, however, cast steel of $\frac{1}{2}''$ minimum thickness be used, C, C_1, and C^2 become 10,400, 52,000, and 34,700 respectively.

The pressure should not exceed 15 if the main body is a single casting.

Steam Pipes.

Board of Trade Rules for the Diameter and Thickness of Steam Pipes.

(i) For copper pipes when the joints are brazed,

$$P = \frac{6000 \times (T - \frac{1}{16})}{D}$$

where P = working pressure in pounds per square inch.
T = thickness in inches.
D = inside diameter in inches.

When the pipes are solid drawn and not over 10 inches diameter substitute in the foregoing formula $\frac{1}{32}$ for $\frac{1}{16}$.

(ii) For wrought-iron pipes made of good material and lap-welded,

$$P = \frac{6000 \times T}{D}$$

This formula does not apply when the thickness is less than $\frac{1}{4}$ inch.

All new copper steam pipes should be hydraulically tested to $2\frac{1}{2}$ to 3 times the working pressure; iron and steel pipes to 3 to 5 times the pressure.

Safety-valves.

Provisions of the Act as regards Safety-valves.

Every steamship of which a survey is required by the Act must be provided with a safety-valve upon each boiler, so constructed as to be out of the control of the engineer when the steam is up; and if such valve is in addition to the ordinary valve, it shall be so constructed as to have an area not less, and a pressure not greater, than the area of and pressure on that valve.

Area of Safety-valves.

When natural draught is used, the area per square foot of fire-grate surface of the locked-up safety valve should not be less than that given in the table on p. 460, opposite the boiler pressure intended, but in no case should the valves be less than two inches in diameter.

When the valves are of common description, and are made in accordance with the tables, it will be necessary to fit them with springs having great elasticity, or to provide other means to keep the accumulation within moderate limits. To find the fire-grate area, the length of the grate to be measured from the inner edge of the dead plate to the front of the bridge, and the width from side to side of the furnace on the top of the bars at the middle of their length.

When forced draught is used, the area required is that found from the tables multiplied by one-twentieth of the

Safety Valve Areas.
(Natural Draught.)

Boiler Pressure	Area of Valve per Sq. Foot of Fire-grate	Boiler Pressure	Area of Valve per Sq. Foot of Fire-grate	Boiler Pressure	Area of Valve per Sq. Foot of Fire-grate
15	1·250	79	·398	143	·237
16	1·209	80	·394	144	·235
17	1·171	81	·390	145	·234
18	1·136	82	·386	146	·232
19	1·102	83	·382	147	·231
20	1·071	84	·378	148	·230
21	1·041	85	·375	149	·228
22	1·013	86	·371	150	·227
23	·986	87	·367	151	·225
24	·961	88	·364	152	·224
25	·937	89	·360	153	·223
26	·914	90	·357	154	·221
27	·892	91	·353	155	·220
28	·872	92	·350	156	·219
29	·852	93	·347	157	·218
30	·833	94	·344	158	·216
31	·815	95	·340	159	·215
32	·797	96	·337	160	·214
33	·781	97	·334	161	·213
34	·765	98	·331	162	·211
35	·750	99	·328	163	·210
36	·735	100	·326	164	·209
37	·721	101	·323	165	·208
38	·707	102	·320	166	·207
39	·694	103	·317	167	·206
40	·681	104	·315	168	·204
41	·669	105	·312	169	·203
42	·657	106	·309	170	·202
43	·646	107	·307	171	·201
44	·635	108	·304	172	·200
45	·625	109	·302	173	·199
46	·614	110	·300	174	·198
47	·604	111	·297	175	·197
48	·595	112	·295	176	·196
49	·585	113	·292	177	·195
50	·576	114	·290	178	·194
51	·568	115	·288	179	·193
52	·559	116	·286	180	·192
53	·551	117	·284	181	·191
54	·543	118	·281	182	·190
55	·535	119	·279	183	·189
56	·528	120	·277	184	·188
57	·520	121	·275	185	·187
58	·513	122	·273	186	·186
59	·506	123	·271	187	·185
60	·500	124	·269	188	·184
61	·493	125	·267	189	·183
62	·487	126	·265	190	·182
63	·480	127	·264	191	·181
64	·474	128	·262	192	·181
65	·468	129	·260	193	·180
66	·462	130	·258	194	·179
67	457	131	·256	195	·178
68	451	132	·255	196	·177
69	446	133	·253	197	·176
70	·441	134	·251	198	·176
71	·436	135	·250	199	·175
72	·431	136	·248	200	·174
73	·426	137	·246	205	·170
74	·421	138	·245	210	·166
75	·416	139	·243	220	·159
76	·412	140	·241	230	·153
77	·407	141	·240	240	·147
78	·403	142	·238	250	·141

estimated consumption of coal per square foot of grate in pounds per hour.

The safety-valve to be fitted with lifting gear, so that two or more valves on any one boiler can be eased together without interfering with the valves on any other boiler. The lifting gear to be arranged so that it can be worked by hand either from the engine-room or stokehole ; safety-valves to have a lift equal to one-fourth their diameter.

Spring Safety-valves.

Spring safety-valves may be fitted in passenger steamers instead of dead-weighted valves, provided that the following conditions are complied with :—

1. That at least two separate valves are fitted to each boiler.

2. That the valves are of the proper size.

3. That the spring and valve be so cased in that they cannot be tampered with.

4. That provision be made to prevent the valve flying off in case of the spring breaking.

5. That screw lifting gear be provided to ease all the valves, if necessary, when steam is up.

6. That the springs be protected from the steam and impurities issuing from the valves.

7. That when the valves are loaded by direct springs, the compressing screw abuts against a metal stop or washer when the load sanctioned by the surveyor is on the valve.

8. That the size of the steel of which the spring is made is found by the following formula :—

FORMULA.

d = diameter or side of square of the wire in inches.
D = diameter of the spring, from centre to centre of wire, in inches.
S = load on the spring in pounds.
k = constant = 8,000 for round and 11,000 for square steel.

$$d = \sqrt[3]{\frac{(S \times D)}{k}}$$

9. That the springs have a sufficient number of coils to allow a compression under the working load of at least $\frac{1}{4}$ diameter of the valve.

Note.—The accumulation of pressure should not exceed 10 per cent of the loaded pressure.

The number of coils required for a given compression, or the compression due to the load, is given by the following formula :—

$$N = \frac{K \times C \times d^4}{S \times D^3} \text{ or } K = \frac{S \times D^3 \times N}{C \times d^4}$$

where N = number of free coils in spring.

K = compression in inches.

d = diameter of steel or side of square *in sixteenths of an inch.*

C = 22 for round and 30 for square steel.

S, D are as above.

The steel of these springs should not be generally less than $\frac{1}{4}$ inch diameter or side.

All safety-valves to be tested under full steam and full firing at least fifteen minutes with the feed-water shut off, and the stop-valve closed.

BOILER MOUNTINGS, SEA CONNEXIONS, ETC.

No arrangement is permissible where the escape of steam from the safety-valve is wholly or partially intercepted by another valve.

A stop-valve should be placed between each boiler and steam-pipe, superheater, or steam receiver.

Each boiler should have a glass water-gauge, at least three test-cocks, and a steam-gauge. If fired from both ends, or of unusual width, an additional water-gauge and set of test-cocks should be provided.

Each boiler should have a suitable check-valve between it and the feed-pipes; all new boilers to have additional separate feed arrangements.

Outlets of water-closet, soil, scupper, lavatory, and urinal pipes below the weather deck should have an elbow of substantial metal other than cast iron or lead. The pipe connected with it should have sufficient bend to allow for working and expansion, as should all pipes connecting the ship's side with the deck, closet, or other fittings. The pipes and valves should be protected from the cargo by a substantial wood or iron casing. Plans of pumping closets below the water-line should be submitted for approval.

All inlets or outlets in the bottom or side of a vessel, near to, at, or below the load water-line, except those above referred to, must have cocks or valves fitted between the pipes and the ship's side or bottom. Such cocks or valves must be attached to the skin of the ship, and be so arranged that they can be easily and expeditiously opened or closed at any time.

All blow-off cocks and sea connexions are to be fitted with a guard over the plug, with a feather-way in the same, and a key on the spanner, so that the spanner cannot be taken out unless the plug or cock is closed. One cock is to be fitted to the boiler, and another cock on the skin of the ship or on the side of the Kingston valve.

In all cases where pipes are so led or placed that water can run from the boiler or the sea into the bilge, either by

accidentally or intentionally leaving a cock or valve open, they should be fitted with a non-return valve and a screw, not attached, but which will set the valve down in its seat when necessary. The only exception to this is the fireman's ash-cock, which must have a cock or valve on the ship's side and be above the stoke-hole plates.

The exhaust pipe for the donkey engine must not be led through the ship's side, but must be led on deck or into the main waste-steam pipe, and in all cases it should have a drain-cock on it.

Spare Gear and Stores to be Carried.

Steamers coming in for survey under the Passenger Acts, and other steamers performing ocean voyages, must carry at least the following spare gear, or its equivalent, which must have been fitted and tried in its place :—

1 pair of connecting-rod brasses.
1 air-pump bucket* and rod with guide.
1 circulating-pump bucket and rod.†
1 air-pump head valve seat, and guard.†
1 set of india-rubber valves (or one-third set metal) for air pumps.
1 circulating-pump head valve seat, and guard
1 set of india-rubber valves (or one-third set metal) for circulating pumps.†
2 main bearing bolts and nuts.
2 connecting-rod bolts and nuts.
2 piston-rod bolts and nuts.
8 screw-shaft coupling bolts and nuts.
1 set of piston springs suitable for the pistons.
1 set of metal feed-pump valves and seats.
3 sets, if of india-rubber, or 1 set if of metal, of bilge-pump valves and seats.
Boiler tubes, 3 for each boiler.
100 iron assorted bolts, nuts, and washers screwed, but need not be turned.
12 brass bolts and nuts, assorted, turned, and fitted.
50 iron „ „ „
50 condenser tubes and 1 hydrometer.
100 sets of packing for condenser-tube ends, or an equivalent.
At least one spare spring of each size for escape valves.
1 set of water-gauge glasses.
$\frac{1}{10}$ the total number of fire bars necessary.
3 plates of iron, and 6 bars of iron assorted.
1 complete set of stocks, dies, and taps, suitable for the engines.
Rachet braces and suitable drills.
1 copper or metal hammer and 1 smith's anvil.
1 screw jack and 1 fitter's vice.
Suitable blocks and tackling for lifting weights.
1 dozen files, assorted, and handles for the same.
1 set of drifts or expanders for boiler tubes.
1 set of safety-valve springs, if so fitted, for every four valves; if there are not four valves, then at least one set of springs must be carried. More than 6 spare springs of the same size need not be provided.

* If valveless, a spare rod and guide only.
† If pump is centrifugal, a spare spindle and disc are required in lieu.

And a set of engineer's tools suitable for the service, including hammers and chisel for vice and forge, solder and soldering-iron, sheets of tin and copper, spelter, muriatic acid or other equivalent, etc., etc.

SIZE OF SHAFTS.

Main and tunnel and propeller shafts should be of at *least* the diameter given by the following formulæ :—

Formula for Compound Condensing Engine with two or more Cylinders, when the cranks are not overhung.

S = diameter of shaft in inches.

d^2 = square of diameter of high-pressure cylinder in inches, or sum of squares of diameters when there are two or more high-pressure cylinders.

D^2 = square of diameter of low-pressure cylinder in inches, or sum of squares of diameters when there are two or more low-pressure cylinders.

P = *absolute* pressure in pounds per square inch, that is, boiler pressure plus 15 lb.

C = length of crank in inches.

k = constant from following table (p. 465).

$$S = \sqrt[3]{\frac{C \times P \times D^2}{k\left(2 + \frac{D^2}{d^2}\right)}} \qquad P = \frac{k \times S^3}{C \times D^2}\left(2 + \frac{D^2}{d^2}\right)$$

Formula for Ordinary Condensing Engines with one, two, or more Cylinders, when the cranks are not overhung.

S = diameter of shaft in inches.

D^2 = square of diameter of cylinder in inches, or sum of squares of diameters when there are two or more cylinders.

P = *absolute* pressure in pounds per square inch.

C = length of crank in inches.

k = constant from following table.

$$S = \sqrt[3]{\frac{C \times P \times D^2}{3 \times k}} \qquad P = \frac{3 \times k \times S^3}{C \times D^2}$$

With one crank, use the constants for 180°.

The portion of the propeller shaft forward of the stern gland, and all the thrust shaft except that in the thrust bearing, may have the same diameter as the intermediate tunnel shafting.

For two Cranks Angle between Cranks.	For Crank and Thrust Shafts.		For Tunnel Shafts.	For Propeller Shafts.
		k	k	k
90°		1·047	1·221	890
100°	For paddle engines of ordinary type, multiply constant of this column suitable for angle of crank by 1·4	966	1·128	821
110°		904	1·055	768
120°		855	997	727
130°		817	953	694
140°		788	919	670
150°		766	894	651
160°		751	877	638
170°		748	867	631
180°		740	864	629
For three Cranks. 120°		1,110	1,295	943

Formula for Turbine Engines.

S = diameter of shaft in inches.

I.H.P. = estimated *maximum* indicated horse-power transmitted through shaft.

R = number of revolutions per minute.

K = 60·3 for tunnel shafts ; 82·8 for propeller shafts.

$$S = \sqrt[3]{\frac{\text{I.H.P.} \times K}{R}}$$

Refrigerators and Distillers.

Machines of ammonia-compression type should be placed in a well-ventilated, isolated compartment, preferably on deck, but an ammonia-absorption machine may be placed in an engine-room if satisfactorily ventilated. A CO_2 machine may similarly be placed in the engine-room if the charge that might be released by a breakdown does not exceed 300 lb.

In emigrant ships, the boiler for supplying steam to the distillers should be built in accordance with the regulations governing the main boilers. The steam for this purpose should not be taken from the main boilers, and no exhaust steam should enter the condenser. The boiler should not be filled or fed with water from the main surface condensers; the introduction of lubricants, tallow, or oil must be avoided. The presence of zinc in such boilers is objectionable. There must be a suitable filter charged with animal charcoal.

Stores to be carried with Distilling Apparatus.

The following list of tools and material must be provided for distilling apparatus :—

1 set of stoking tools.
1 scaling tool.
1 spanner for boiler doors.
1 set of fire bars, suitable for boiler.
1 14 in. flat bastard file.
1 14 in. half-round file.
1 10 in. round file.
3 file handles.
2 hand cold chisels.
1 chipping hammer.
1 pair of efficient gas tongs.
1 soldering iron.
10 lb. of solder.
2 lb. of resin.
6 gauge glasses.
24 india-rubber gauge-glass washers.
30 bolts and nuts, assorted.
1 slide rod for donkey pump.
5 lb. of spun yarn.
10 lb. of cotton waste.
1 deal box with lock complete.
2 gallons of machinery oil.
1 can for machinery oil.
1 oil-feeder.
1 small bench vice.
1 ratchet brace.
4 drills, assorted.
1 set of dies and taps suitable for the bolts.
2 glass salinometers.
1 hydrometer and pot.
1 shifting spanner.
1 lamp for engineer.
Animal charcoal sufficient to charge the filter at least twice.
And other articles that the particular distiller and boiler supplied may, in the surveyor's judgment, require.

BOARD OF TRADE REGULATIONS FOR MOTOR PASSENGER VESSELS.

The regulations governing passenger steamships apply, as far as they are applicable, to motor- and electric-boats which carry more than twelve passengers. The following special requirements apply to boats using petrol or other grade of petroleum :—

Oil Tank.—To be well and substantially constructed, and of reasonable size. If of iron or steel, to be galvanized externally. Tank and connexions to be quite oil-tight, and to be tested hydraulically to a head of 15 feet of water.

The tank should be securely fixed on a lead-lined or metal tray, above the deep load-line, with drain-pipes leading overboard.

The arrangements for filling should prevent oil readily spilling into or lodging in any part of the vessel; the petrol vapour displaced when filling should be led overboard. The wood deck, if any, surrounding the inlet pipe should be covered with sheet metal. Each inlet or outlet to the tank should be covered with a removable wire-gauge diaphragm; the filling pipe should have a screwed cap. The tank to be filled when no passengers are on board. No loose cans of petrol to be carried in the boat.

An open pipe with gauze, a light spring safety-valve, or a fusible plug to be provided for relieving the pressure in case of fire in the tank.

Pipe Arrangements.—The pipe conveying the petrol to the carburetter to be of solid-drawn copper, with a flexible bend, and with a cock or valve at each end, one on the tank and the other on the carburetter; the joints to be accessible so that they can be kept quite oil-tight. Soft solder joints are unsatisfactory.

The air inlet to the carburetter should have a wire-gauge diaphragm, and be carried to the ship's side or to a reasonable height above the carburetter, so that there will be no danger of ignition of any petrol vapour that may escape when the engine is stopped.

The carburetter should desirably be of such a type that, when the motor is stopped, the supply of petrol to the carburetter will be shut off automatically. A suitable receptacle may be necessary to the carburetter to prevent an overflow of petrol from the latter into the launch when the engine is stopped; this should have a narrow neck with a wire-gauze covering at the mouth with means of draining it.

The exhaust pipe should be efficiently cooled to prevent danger.

Ignition.—An exposed spark gap is not permitted in the engine-room, and the leads from the accumulators or generators to the sparking plugs should be efficiently insulated, well secured, and protected from moisture, particularly when the high tension system of electrical ignition is adopted. Ignition tubes should not be passed unless oil having a higher flash point than 73° Fahrenheit is used. If blow lamps are used for this class of oil, they must be fixed and the flame enclosed.

Motor Compartment, Ventilation, etc.—If the motor, or petrol tank, is situated below deck, it should be confined within a separate water-tight and well-ventilated compartment, in which no stove or other apparatus for containing fire should be placed. The compartment should have at least two cowl ventilators, arranged to prevent the accumulation

of oil vapour in the lower part of the space, to which part one of the ventilators should extend. Any enclosed space within which the motor, or tank, is placed should be similarly ventilated except in small open launches where louvres, or other suitable openings, can be provided, in which case one cowl ventilator may be sufficient. In such a vessel, the space occupied by the motor, petrol tank, etc., should, preferably, be at the after end of the boat, and separated from the space allotted for the accommodation of passengers and crew by a substantial bulkhead as high as the seats, and water-tight for at least the lower half; but, if it is specially desired to place the motor amidships, or forward, either arrangement may be allowed, provided a bulkhead, formed in the manner stated, is placed between the motor space and the passenger or crew space.

Tray for Motor.—If the vessel is of wood, a metal tray which can readily be cleaned should be fitted under the motor; if there are flooring boards, they should be closely fitted, but removable to facilitate cleaning, etc.

Miscellaneous.—The machinery to be fixed where necessary to protect persons in the boat. The cylinders to be hydraulically tested to twice their maximum working pressure. and the silencer and exhaust pipe to one-fourth of that applied to the cylinders.

Boats less than 30 feet long should carry at least one efficient chemical fluid fire-extinguisher, and a box of sand of one cubic foot capacity with a suitable scoop. In larger boats or in special circumstances additional appliances may be required. Full directions should be attached to the extinguishers; and these should be protected, but placed ready for immediate use. The extinguishing medium should be harmless to the person.

Motor-launches.

Special certificates are issued for open motor-launches to proceed on short excursions at sea, not more than 3 miles from the starting-point; the boats may then only ply in summer during daylight and in fine weather. The general requirements for passenger ships apply as far as they are applicable.

Number of Passengers.—This must not exceed the clear area of the space available in square feet, divided by four. In measuring the length of the space, that necessary forward for anchor and cable and aft for steering arrangements is to be deducted as well as the overall distance apart of the bulkheads enclosing the motor space. The breadths are to be taken between the backs of the side benches, or the inside of the half deck, whichever is least. In any case the number of passengers should not exceed the seating accommodation, which is equal to the total length of fixed seats in feet divided by

1·5. The breadth of the boat should be sufficient to satisfy the surveyor that all the passengers can be safely carried.

Freeboard.—When the boat is loaded with weights equivalent to 140 lb. for each passenger or member of crew, together with the complete outfit and necessary fuel, the clear height of side above water at the lowest point should be not less than 15 inches for boats 20 feet long, or less, 22 inches for vessels 40 feet long, and proportionately for lengths between 20 and 40 feet. The length is that from side to stem to after side of sternpost. The clear side is measured from top of covering board, wash strake, or half deck coaming, whichever is the highest.

Height of Sides and Rails.—The top of the covering board, wash strake, or upper edge of covering should not be less than 30 inches above the flooring boards in boats 20 feet in length, or less, 36 inches in boats 40 feet long or more, and proportionately for lengths between 20 and 40 feet. If necessary a rail is to be fitted above the covering board, sufficiently high to comply with the above regulation.

Life-saving Appliances.—These, together with sound signals, are to be provided. Also two chemical fire-extinguishers, sand, a compass, anchor and cable, at least three oars and rowlocks, boat-hook, painter, heaving line, bailer, and (for large boats) bilge-pumps.

At least two competent men—a seaman and an engine-driver—should be employed in each boat.

BOARD OF TRADE REGULATIONS FOR SHIPS.

These certificates are granted as follows :—

1. Foreign-going steamers.
2. Home-trade passenger steamers (i.e. between Great Britain, Ireland, and within the limits of River Elbe and Brest).
3. Excursion steamers plying along the coast during daylight and in fine weather between April 1 and October 31, within the limits stated below (see C after each port).
4. Steamers plying in partially smooth water (see B after each port).
5. Steamers plying in smooth water (see A after each port).

Note.—A "sea-going" vessel includes surveys 1, 2, or 3.

PLYING LIMITS ASSIGNED TO PORTS IN THE UNITED KINGDOM.

Note.—After each port (in italics) follow the smooth-water limits (denoted by A), the partially smooth limits (denoted by B), and the excursion limits (denoted by C).

Eastern Coast of Scotland.

Cromarty: (A) In Cromarty Firth but not below Cromarty. *Inverness:* (A) Fort George to Chanonry Point to Fort William; (C) Lossiemouth or Dunrobin. *Banff:* (C) Peterhead or Lossiemouth. *Peterhead:* (C) Aberdeen or Banff. *Aberdeen:* (A) Inside the Harbour; (C) Peterhead or Montrose. *Montrose:* (C) Dundee or Aberdeen. *Dundee:* (A) Dundee to Newport Ferries; (B) Broughty Castle to Tayport; (C) Montrose or Leith. *Queensferry:* (A) Above the Forth Bridge; (B) Kirkcaldy to Portobello; (C) Berwick-on-Tweed or Dundee. *Leith:* (B) Kirkcaldy to Portobello; (C) Berwick-on-Tweed or Dundee.

North-Eastern Coast of England.

Berwick-on-Tweed: (A) Spittal Point; (C) North Berwick or Newcastle. *Amble:* (A) Amble Bar; (C) St. Abb's Head or Middlesbrough. *Blyth:* (A) Inside the Pier Heads. (C) Berwick-on-Tweed or Whitby. *Newcastle, North and South Shields:* (A) Inside the Tyne Pier Heads; (C) Berwick-on-Tweed or Scarborough. *Sunderland:* (A) Inside the Sunderland Pier Heads; (C) Berwick-on-Tweed or Scarborough. *Seaham:* (C) Berwick-on-Tweed or Scarborough. *Hartlepool, East:* (A) Hartlepool Bar; (C) Amble or Bridlington. *Hartlepool, West:* (C) Amble or Bridlington. *Stockton:* (A) Fourth Buoy; (C) Amble or Bridlington. *Whitby:* (A) Inside the Whitby Pier Heads; (C) Bridlington or Newcastle.

Eastern Coast of England.

Scarborough: (C) Newcastle or Hull. *Hull:* (A) In Winter, Whitten Ness to Brough; (B) in winter, New Holland to Paull; (C) Lynn or Scarborough. (A) In Summer, above Hull and New Holland; (B) in Summer, Cleethorpes Pier to Patrington Church. *Goole:* (A–C) Same as Hull. *Gainsborough, Lincoln, Nottingham, York:* (A–B) Same as Hull; (C) Spurn Point or Donna Hook. *Grimsby:* (B) In Summer, Cleethorpes Pier to Patrington Church; (C) Same as Hull. *Boston:* (A) Inside the New Cut; (C) Cromer or Hull.

London District.

Wisbech: (A) Inside Wisbech Cut; (C) Cromer or Hull. *King's Lynn:* (A) Inside Lynn Cut; (C) Cromer or Hull. *Norwich or Yarmouth:* (A) On all the inland navigation from Norwich to inside the piers at Yarmouth or Lowestoft; (B) S.W. Barnard Buoy to the North Cockle Buoy inside the Banks; (C) Cromer or Walton-on-the-Naze. *Lowestoft:* (A–C) Same as Norwich or Yarmouth. *Aldeborough and Orford:* (A) Inside the Rivers Alde and Ore. *Harwich or Ipswich:* (A) Inside Landguard Fort; (B) Walton-on-the-Naze to Landguard Fort; (C) London or Yarmouth. *Maldon:* West Mersea Point to Bradwell Point at the mouth of the River Blackwater. *Burnham-on-the-Crouch:* (A) Hollywell Point to Foulness Point; (B) Clacton Pier to Herne Bay Pier; (C) Dover or Harwich. *London:* (A) Gravesend; (B) North side—for vessels of approved construction and of not less than 15 knots speed, from April 1 to September 30, Girdler Lightship to the North-east Gunfleet Buoy, and thence to Walton-on-the-Naze; for other vessels, Clacton Pier to Herne Bay Pier; south side—Southend Pier to the Girdler Lightship and from the Girdler Lightship to Foreness; (C) Dover or Harwich. *Rochester:* (A) Sheerness and Whitstable inside Sheppey; (B) Clacton Pier to Herne Bay Pier; (C) Dover or Harwich. *Dover:* (B) For tenders—within a radius of two miles from the outer end of Prince of Wales Pier, during fine weather only; (C) Newhaven or Sheerness.

Folkestone: (C) Newhaven or Sheerness. *Newhaven:* (C) Portsmouth or Dover. *Littlehampton:* (A) Above Littlehampton Pier; (C) Poole or Rye. *Langston and Chichester:* (A) From a line drawn from the north point of Cumberland Fort to Gunner Point across the entrance of Langston Harbour to a line drawn from the East Saltern to the Watch House: across the mouth of Chichester Harbour. *Portsmouth:* (A) Inside Portsmouth Harbour; (B) St. Helens and the Needles within the Isle of Wight and to Langston Harbour; for small launches not carrying boats—in summer, a line from Brading Harbour to Langston Harbour inside the Isle of Wight to Hurst Castle; in winter, Spithead; (C) Newhaven or Weymouth. *Southampton:* (A) Calshot Castle; (B–C) Same as Portsmouth. *Cowes:* (A) Between East and West Cowes within the River Medina. *Christchurch:* (A) Within the Bar. *Poole:* (A) Inside the Harbour; (C) Weymouth or the Nab. *Weymouth:* (B) Portland Harbour; (C) Portsmouth or the Start.

South and South-West of England.

Exeter: (A) Inside the Bar; (C) Weymouth or Plymouth. *Teignmouth:* (A) Within the Harbour; (C) Weymouth of Plymouth. *Torquay:* (C) Weymouth or Plymouth. *Dartmouth:* (A) River Dart; (C) Weymouth or Plymouth. *Plymouth:* (A) From the inside of Drakes Island to Mount Batten Pier; the River Yealm within a line from Warren Point to Misery Point; (B) Cawsand to Breakwater and Breakwater to Staddon Pier; for tenders to ocean-going steamers—Rame Head to Stoke Point, during fine weather only; (C) Exeter or the Lizard. *Fowey:* (A) Inside the Harbour; (C) Falmouth or Plymouth. *Par:* (C) Falmouth or Plymouth. *Falmouth:* (A) Zoze Point to Pendennis Point; (B) in summer, during daylight and in fine fine weather only—Nare Point to St. Anthony's Point; (C) Start Point or Penzance. *Penzance:* (C) Falmouth or St. Ives. *St. Ives:* (C) Padstow or Penzance. *Padstow:* (A) Padstow Harbour, above Gun Point and Brae Hill; (B) Stepper Point to Trebetherick Point; (C) St. Ives or Barnstaple, including Lundy Island. *Barnstaple:* (A) Inside the Bar; (C) Padstow or Bridgwater, including Lundy Island.

South Wales.

Bridgwater: (A) Inside Stert Point; (B) Within the Bar; (C) Ilfracombe or Swansea. *Bristol:* (A) Avonmouth Pier to Wharf Point; (B) in summer, Barry Dock Pier to Steepholm, thence to Bream Down; in winter, for tenders to ocean-going steamers—to King's Roads and not below Walton Bay, during fine weather only; (C) Ilfracombe or Swansea. *Gloucester:* (A) River Severn or Avon to Sharpness Point, via Gloucester Canal; (B) in summer, Barry Dock Pier to Steepholm, thence to Bream Down; (C) Watchet or Barry Dock. *Chepstow:* (A) River Wye above Chepstow; (B) same as Gloucester. *Cardiff:* (A) Low-water Pier Head to the Lifeboat House near Penarth Dock entrance; (B) same as Gloucester; (C) Tenby or Ilfracombe. *Barry Dock:* (A) Inside Dock; (B) same as Gloucester; (C) Milford or Ilfracombe. *Neath:* (A) Inside the Bar; (C) Barnstaple or Milford. *Swansea:* (C) Barnstaple or Millwall, including Lundy Island. *Milford:* (A) Hubberston Beach to Angle Point; (B) South Hook Point to Thorn Island; (C) Swansea or Cardigan. *Fishguard:* (B) For tenders—within a radius of 3 miles from the outer end of the breakwater in Fishguard Bay, during fine weather only; (C) Barmouth or Tenby. *Cardigan:* (A) Inside the Bar; (C) Portmadoc or Milford. *Barmouth:* (A) Inside Barmouth Ferry; (C) Cardigan or Bardsey Island.

Liverpool District.

Portmadoc: (A) Inside the Bar Buoy; (C) Cardigan or Carnarvon. *Holyhead:* (A) Inside the Breakwater; (C) Liverpool or Portmadoc or round the Island of Anglesea. *Carnarvon:* (A) Menai Straits to Aber Menai or Beaumaris; (B) Menai Straits, from Carnarvon Bar to Puffin Island; (C) same as Holyhead. *Conway:* (A) Mussel Hill to Tremlyd Point; (C) same as Holyhead. *Chester:* River Dee, not below Connah's Quay; (B) inside the West Hoyle Bank; (C) Barrow, Holyhead, or Carnarvon. *Liverpool:* (A) The Rock Light House; (B) in summer, Formby Point to Hilbro' Point; for tenders to ocean-going steamers, within a radius of 3½ miles of Formby Lightship, during fine weather only; the Bell Buoy and Bar Lightship for tugs; (C) Barrow, Holyhead, or Carnarvon. *Preston:* (A) Lytham; (B) Southport or Blackpool, inside the Banks; (C) Llandudno or Barrow. *Fleetwood:* (A) Low Light to Knotend Pier; within Fleetwood Harbour, for tugs plying as tenders; (C) Whitehaven or Liverpool. *Lancaster:* (A) Sunderland Point to Chapel Point; (C) Whitehaven or Liverpool. *Morecambe Bay:* (A) For tenders, within a radius of 3 miles of Heysham Piers; (B) in summer, from Heysham to Sunderland Point and to Morecambe and Grange; (C) Whitehaven or Liverpool. *Bowness:* (A) Anywhere on the Lakes. *Barrow:* (A) Inside Walney Island; (C) Whitehaven or Liverpool. *Douglas:* (A) From Battery Pier to Victoria Pier; (C) round the Island. *Whitehaven:* (C) Barrow or Carlisle. *Carlisle:* (A) Above Port Carlisle; (B) Southerness to Silloth; (C) Whitehaven or Port Whithorn.

Western Coast of Scotland.

Dumfries: (A) Inside Aird Point and Glenhaven Point; (B) Southerness to Silloth; (C) Wigtown or Whitehaven. *Wigtown:* (C) Stranraer or Dumfries. *Stranraer:* (A) Inside Cairn Ryan; (B) Loch Ryan, from Kinnaird Point to Milleur Point; (C) Wigtown or Greenock. *Ayr:* (A) Inside the Bar; (C) Stranraer or Glasgow. *Ardrossan:* (C) Stranraer or Glasgow. *Glasgow:* (A) In winter, Cloch Lighthouse to Dunoon Pier; in summer, Bogany Point, Isle of Bute, to Skelmorlie Castle and Ardlamont Point, inside the Kyles of Bute; (B) Skipness to Fairlie Head round the Island of Bute; (C) Stranraer to Campbeltown. *Campbeltown:* (A) Inside the Harbour, but not outside Davaar Island; (C) Glasgow only. *Oban:* (B) Inside the Island of Kerrera to Dunstaffnage Point; (C) Crinan, Tobermory, or Fort William. *Ballachulish:* (A) Within Loch Leven and not outside Peter Straits. *Fort William:* (A) On the Canal to Inverness; (C) Crinan or Tobermory. *Kyle:* (B) Through Loch Alsh to the Head of Loch Duich.

Ireland.

Larne: (A) Larne Pier to the Ferry Pier on Island Magee. *Belfast:* (A) Holywood to Macedon Point; (B) in summer, Carrickfergus to Bangor; for tenders to ocean steamers only, within a radius of 3 miles from Carrickfergus, during fine weather; (C) Rathlin Island or Killough. *Carlingford Lough:* (A) Greencastle Point to Greenore; (C) Drogheda or Strangford Lough. *Drogheda:* (A) Crook Point to Burrow Point; (C) Dublin or Warren Point, Carlingford Lough. *Dublin:* (A) Inside the Pier Heads; (B) in summer, Dalkey Island to Bailey Point; (C) Drogheda or Arklow. *Wexford:* (A) Inside Ely House; (B) Raven Point to Rosslare Point; (C) Arklow or Waterford. *Waterford:* (A) Passage; (B) in summer, Dunmore to Hook Point; in winter, Geneva Barrack to Duncannon Light; (C) Wexford or Youghal. *Youghal:* (A) Ferry Point to Green Park; (C) Waterford or Kinsale. *Cork:* Camden to Carlisle Forts; (B) for tenders to ocean steamers only, within a radius of

3 miles from Roches Point, during fine weather; (C) Dungarvan or Galley Head. *Bantry Bay:* (A) Inside Bear Island, inside Whiddy Island, Glengariff Harbour, Inside Corrid Point; (C) Galley Head or Valencia Harbour. *Limerick:* (A) Foynes; (B) Scattery Lighthouse to Carrig Island; (C) Loop Head or Kilmore Head. *Galway:* (A) Lough Corrib; (B) Black Rock Beacon to Kilcolgan Point; (C) Kilkieran or Liscannor Bays inside the Arran Isles. *Killary Bay:* (A) Inside Inishbarna Islands. *Sligo:* (A) The Western extreme of Oyster Island; (B) Raghly Point to Black Rock Point; (C) Donegal or Ballina. *Enniskillen:* (A) Lough Erne. *Donegal:* (A) Inside the Bar; (C) Sligo or Rathlin O'Birnie Island. *Lough Swilly:* (A) Buncrana to Muckarnish Point; (B) Dunree Head to Port Salon; (C) Portrush or Tory Island. *Londonderry:* (A) Magilligan Point to Greencastle; (B) For tenders to ocean steamers only, within a radius of 3 miles from Innishowen Lighthouse during fine weather; (C) Buncrana in Lough Swilly or Rathlin Island.

Examination of Hulls.

Passenger vessels carrying more than twelve passengers are to be surveyed once a year in dry dock. The survey concerns the condition of hull and machinery; the equipment of boats, lifebuoys, lights, signals, compasses, and shelters for deck passengers; the limits of time and place; the number of passengers at various seasons in each port available; the certificates of the master, etc.; the safety-valves and fire-hose.

New steamships are to be surveyed before the hull is complete, and before the paint and cement are put on, as well as when complete.

An efficient and water-tight engine-room and stoke-hole bulkhead, as well as a collision water-tight bulkhead, and an after water-tight compartment to enclose the stern-tube of each screw shaft, should be fitted in all sea-going steamers.

The collision bulkhead * should be at least $\frac{1}{20}$ length abaft the stern. It should not be pierced for openings or pipes. In new ships the foremost bulkhead should extend to the upper deck; and the aftermast to a watertight flat, if any, otherwise to the upper deck. In awning-decked vessels the remaining bulkheads may be terminated at the deck below the upper deck; otherwise they should extend to the upper deck. (In shelter-deck vessels this may be the deck below the shelter deck if fairly high above water.)

In certain smooth or partially smooth water-vessels, the above arrangement may be modified in special cases; in all new vessels, however, except steam launches plying in very narrow waters, an efficient collision bulkhead must be provided.

In sea-going screw vessels there should be, commencing from the stuffing-box bulkhead, either a W.T. tunnel to the

* All bulkhead regulations are now subject to revision. In the report of the Committee on Subdivision of Ships (Foreign and Home Steamers) the spacing of bulkheads is determined by flooding curves that are constructed for standard ships and can be extended to all ordinary vessels.

after engine-room bulkhead, or a W.T. compartment of length 12 times the shaft diameter. The fore bulkhead should have a stuffing box round the shaft; this bulkhead to be either pierced, with a W.T. door capable of being quickly opened and closed from the upper deck, or a W.T. trunk up to the upper deck should be fitted. All such work to be of steel or iron.

W.T. doors, which can be opened from the upper deck, to be fitted to all openings in W.T. bulkheads. It is desirable that their closing edges be bevelled, and that vertical doors be used with coal bunkers.

Midship sections of all new vessels are to be submitted unless the Surveyor considers that the scantlings are equivalent to the standard laid down in the Freeboard Tables.

All openings in the weather deck of sea-going ships should have W.T. covers which can be expeditiously shipped. Those over stokeholds, around funnels, and engine-room skylights should have gratings as well as iron or steel covers. Openings in the main and lower decks should also be fitted with gratings or hatch covers and tarpaulins, which can render them W.T. The coamings of all such openings should be of sufficient height and strength.

Side Scuttles.—These and the dead lights should be of appropriate strength. Cast iron is unsuitable for scuttles, except in "smooth-water" vessels of less than 50 tons net register; it may be used for dead lights. Cast steel and malleable cast iron may be used; the former material must be tested by bending if the centre of the freeboard disc is less than 10 feet below the sill; the scuttle frames should stand bending through 20° without fracture. Similarly malleable cast-iron frames and plugs below this height should stand bending through 15° and 30° respectively without fracture.

Scuttles whose sills are less than 6 inches above the centre of disc, or Indian summer line (if any), are subject to the following special requirements: Their diameter must not exceed 10 inches in the clear. They must be hinged to a strong frame of naval brass, gunmetal, or cast steel, the flange against ship's side being $\frac{9}{16}''$ thick; the securing bolts to side being ten in number, $\frac{5}{8}''$ minimum diameter with one screw in way of hinge, or equivalent W.T. arrangement. The glass should be 1″ thick, secured in a strong holder of gunmetal or naval brass. The deadlights should be strongly ribbed; to be made of a material allowable for the frame; minimum thickness to be $\frac{5}{8}''$; they must be W.T. The glass holder and deadlight should be secured by five $\frac{5}{8}''$ naval brass securing bolts—preferably three for the former—hinged on similar pins, with plain, square, or hexagonal nuts. An outer cover or plug cut from $\frac{5}{8}''$ steel plate to be made and machined to protect the glass; this must be

shipped from inboard, and recessed at least $\frac{1}{8}''$ below the surface of the outside plating. The naval brass to be of Admiralty composition, with a breaking strength of 25 tons per square inch; that of the gunmetal being 14 tons per square inch.

Deadlights and Outer Plugs.—In addition to those above specified they must be fitted as follows: In sea-going ships (*a*) all scuttles below upper deck nearer the forward end than $\frac{1}{8}$ length; also in forecastles unless open at after end or situated below an awning or shelter deck; (*b*) all scuttles below upper deck in spaces for accommodation of crew; (*c*) all scuttles in spaces adopted for stowage of cargo, fuel, or stores are to have efficient hinged W.T. deadlights.

Vessels on foreign-going or winter home-trade service are to have similar deadlights to *all* scuttles whose sills are less than $\frac{1}{10}$ the registered breadth above the deepest load line in salt water. In vessels less than 40 feet or more than 90 feet broad this distance to be 4 and 9 feet respectively. All higher scuttles in spaces fitted for accommodation of passengers, officers, etc., shall, if without deadlight, have a substantial outer plug stowed in close vicinity to the scuttle. No other deadlights or plugs need be fitted with scuttles of usual sizes and thickness. The upper deck is throughout defined as with reference to bulkheads (p. 473).

New vessels for home summer, or excursion service, without cargo, should have deadlights according to (*a*) and (*b*) above. All in engine-room, boiler-room, and coal-bunkers, should also have deadlights; those in spaces for passengers, officers, etc., are to have one outer plug stowed between each two scuttles.

Vessels not plying outside the partially smooth limits need have no plugs or deadlights if the glass of the scuttles is sufficiently thick.

Miscellaneous.—The windows of saloons should have shutters, at least one to every two windows, or every four windows in home trade and excursion vessels respectively.

Cast steel for important parts, such as stems, rudders, steering quadrants, or tillers, must be tested according to p. 450. For side scuttles see above; other castings are tested for ductility.

Pumps, Sluice Valves, Steering Gear, etc.

There must be in each compartment, including the engine-room, a hand-pump of sufficient size which can be worked from the upper deck. Their suctions should be at the after end and on the middle line; if this latter be impossible in midship compartments, there should be one pump on each side. If the pumps are not on the upper deck, they

should be of closed top type, with discharge pipes well above the deep load line.

In lieu of the hand-pumps, two rotary pumps, may be fitted, either of which must be capable of drawing from any hold or machinery compartment. Alternatively in vessels having two separate W.T. boiler-rooms and one W.T. engine-room, two steam pumps in separate compartments may be used; they must be capable of pumping from any bilge suction, and these latter must be capable of being shut off in any compartment flooded. There must be a sounding tube fitted from the upper deck to each compartment. Pipes connected with pumps worked by the engines, are to be arranged so that each compartment can be pumped out separately by the engines as well as by the deck pumps.

In new ships the suctions must have non-return valves where necessary to prevent water flowing through them from a bilged compartment to another; and the controlling valves must be workable from the upper deck. In machinery bilges there should be mud-boxes always accessible; hold and tunnel well suctions should have a suitable rose box or strum.

A spare tiller, relieving tackle, etc., should be carried in all sea-going steamers. The helmsman should have a clear view ahead. In high speed boats the heel on putting helm over at full speed should be measured.

A deep-sea lead-line of at least 120 fathoms, a lead of at least 28 lb. weight and a suitable reel, together with at least two hand lead-lines of 25 fathoms each, and leads of at least 7 lb. each, should be supplied to all foreign-going steamers.

In home-trade steamers two hand lead-lines of 25 fathoms each, and leads of 7 lbs. each, must be supplied.

For a first-class certificate of registry (i.e. twelve months) double the number of leads and lines must be supplied. Equivalent sounding machines are acceptable in lieu.

Lead lines are usually marked as follows:—

At 2	fathoms	a piece of leather split into two strips.	
,, 3	,,	,, ,, ,,	three strips.
,, 5	,,	,,	white bunting.
,, 7	,,	,,	red bunting.
,, 10	,,	,,	leather with a hole.
,, 13	,,	,,	blue bunting.
,, 15	,,	,,	white bunting.
,, 17	,,	,,	red bunting.
,, 20	,,	a strand with two knots tied in it.	

Fire Hose.

A fire hose adapted for extinguishing fire in any part of the ship, and capable of being connected with the engines of the ship, or with the donkey engine if it can be worked from

the main boiler, should be supplied in all sea-going ships. If metal pipes be fitted, they should have valves controlling on deck the water-supply when charging hoses; it should be possible to reach any part of the vessel's holds, bunkers, or living quarters simultaneously with two lengths of hose.

Distress Signals.

All sea-going passenger and emigrant ships must carry—(1) One gun $3\frac{1}{2}$ inches bore or more, or one mortar $5\frac{1}{2}$ inches bore, with twenty-four charges (16 oz. of powder each) for foreign-going ships and twelve for others. All accessories necessary must be carried. Alternatively socket or sound signal rockets of equal number may be carried. (2) Two deck flares, burning forty minutes except for daylight excursion vessels. (3) Twelve rockets or shells, each having 16 oz. of composition. Alternatively as with 1. (4) A continuous sounding fog-signal apparatus.

In addition six lifebuoy lights burning forty minutes. (*a*) gunpowder, (*b*) rockets, (*c*) socket signals, (*d*) flares and buoy lights, (*e*) other pyrotechnic signals must each be stowed in separate magazines. The powder should be kept in flannel bags contained in a strong copper magazine.

Compasses.

Each foreign-going steamer is to have three compasses and binnacles, of which one is to be a standard compass. Vessels in partially smooth water are to have one compass.

Master's and Crew Spaces.

The measurements for crew must not include useless spaces, e.g. under ladderways or galleys; the tumble home, except that more than 5 ft. 6 in. above the floor must not be included. The quarters must be strongly built, free from odour from lamp-rooms or paint stores, or from other effluvium, and properly lighted (when clear it should be possible to read a newspaper with one-third of the light cut off). There should be complete protection from weather and sea. Cables led through the spaces should be cased.

Ventilation should be complete and thorough, with two ventilators (one inlet, one outlet) to each space, one of which extends to the lower edge of beams. The tops of these should be fitted preferably with revolving cowls (which may be portable), as high as the bulwarks; mushroom ventilators, minimum height 30 inches or height of bulwarks, may be fitted, but are not desirable except for deck houses. When practicable all cabins should have a cowl or swan-neck ventilator. Skylights, scuttles, companions, and doors, although frequently useful as auxiliaries, cannot be accepted as efficient ventilators in all weathers. Privies should be suitably ventilated. In vessels liable to be sent to the Tropics, provision

should be made for introducing a windsail 18 inches or more diameter over each space; this may be at a skylight or a hatch. Stove funnels must have outlets distinct from the ventilators.

All iron decks in crew spaces must be sheathed with wood at least 2½ inches thick, properly laid and caulked ; no portion of a bunk may be placed directly over an iron fitting preventing the complete sheathing of the deck. Lining under decks or at sides is undesirable ; but bunk boards 18 inches high should be placed to protect occupants from condensation at the sides.

Spaces should be 5 ft. 6 in. high in the clear to underside of beams ; the lowest bunk must be 12 inches above the floor, and the bottoms of the bunks must be 2 ft. 6 in. from one another and from the deck. Their length must be at least 6 feet.

Space must be drained by pipes, provided with plugs and lanyards. Wood bulkheads to be tongued and grooved and made of well-seasoned material ; against the galley and privies it should be doubled with felt between ; against a donkey boiler space or the engine and boiler casings a wood lining with 3 in. space filled with non-conducting material to be fitted.

There should be one privy for every ten men, exclusive of officers ; if over 100 men add 4 per cent for each additional 100 or part of 100. With less than twenty men, including officers, two privies are sufficient ; with less than ten, one only. With trough closets for Lascars, a linear 18 inches clear opening is equivalent to one privy. Privies should be efficient, and well separated from crew spaces ; if they open directly into a crew or officer's space, no tonnage deduction can be claimed.

To obtain the number of seamen and apprentices, measure the clear area available, excluding useless spaces (see paragraph 1) and encumbrances such as hatchways, trunks, etc. The cubic capacity is equal to the clear area multiplied by the height from deck to deck at the middle line. There must always be bunks and hammock fittings equal in number to the accomodation certified, but they are not deducted as encumbrances in the space except in cabins.

In all ships the number of men in each space must not exceed one per 12 square feet clear area, and one per 72 cubic feet capacity, including only such spaces as are used for sleeping. In new ships (except fishing boats and ships of not more than 300 tons net), there must also be sufficient mess room, bathroom, and wash-place accommodation to bring up the total space (inclusive of these) to 15 square feet and 120 cubic feet per man. The latter regulation does not apply to Lascars, but in cabins there should be 15 square feet per man exclusive of the bunk.

PASSENGER ACCOMMODATION.

General.

Foreign and home-trade steamers to be properly lighted and ventilated by day and night, with proper means of access, wherever passengers are accommodated. Spaces not naturally lighted must be lighted electrically, not by oil lamps. There should be a good air supply in bad weather under closed hatches. Electric lighting should be arranged to minimize risk of fire, with the source sufficiently high to prevent the probability of the light being extinguished after a slight accident. The lamp-room, if near the passengers' quarters, should be separated by a fireproof bulkhead. Decks under and above the passengers' quarters must be sheathed, if of metal (except from May 1 to August 31); all floors being properly laid and caulked. In new foreign vessels the overflow pipes to drinking tanks must not discharge into the bilges, and the air pipes must be led to the upper deck.

Rails and stanchions must be 3 ft. 6 in. high, and not more than 9 in. apart unless provided with strong netting. The freeing ports of close bulwarks (which must also be 3 ft. 6 in. high) should be protected by grids. In vessels plying in smooth or partially smooth water the height of rails or bulwarks (top of rail above top of deck, not including waterway) should be as follows:—

Registered Length of Vessel in Feet.		Under 50.	50 to 70.	70 to 90.	90 to 130.	130 to 170.	170 and over.
		ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Height of rail	Partially smooth limits	2 9	2 10	3 0	3 2	3 3	3 4
	Smooth water limits	2 6	2 8	2 10	3 0	3 2	3 3

Passengers in Foreign-going Steamers.

The weather deck, and the surface of the poop, forecastle, and bridge deck, are never to be included in the measurements for passengers; nor are the poop, round house, or deck house, unless they form part of the permanent structure of the vessel.

Foreign-going steamships carrying more than twelve passengers are to be measured as follows:—

Saloon or 1st Class, and Second Class.—The number of fixed berths or sofas that are fitted determine the number of passengers to be allowed.

Sufficient light and ventilation and a reasonable amount of floor space must be provided.

3rd Class.—The number may be determined in like manner if berths are fitted; if not, the net area of the deck, multiplied by the height between decks and the product divided by 72, gives the number to be allowed. The breadth of the deck is taken inside the water-way, or at the greatest tumble-home of the side, if there is any. The height between decks must not be less than 6 feet.

When cargo, stores, etc., are carried in the space measured for passengers, one passenger is to be deducted for every 12 superficial feet of deck space so occupied.

Passengers in Home-Trade Sea-going Steamers.

Fore-cabin passengers include all passengers except those entered as after-cabin or saloon passengers in the waybill.

In new vessels closets must be provided on the following scale:—

Passengers . . .	133	200	325	450	575	700	825
Closets	2	3	4	5	6	7	8
Urinals or extra closets	—	—	1	1	2	3	4

If, however, two or more classes of passengers are taken, each class need have only six closets and two urinals. Two closets, at least, must always be provided. A fair proportion of the closets must be allotted solely to women and children, and reasonable privacy afforded. Closets must be clean, well lighted, ventilated, drained, and protected from weather and sea. Additional earth-closets may be temporarily installed, but for one month only, or less.

The number of passengers to be carried in the after-cabins, fore-cabins, state-rooms, etc., is determined by the number of berths, or sofas, properly constructed for sleeping berths, provided there are 72 cubic feet of space for each passenger berthed in each state-room or cabin. The floor of state-rooms is never to be measured, but so much of the floor of the after-saloon as is not covered by tables, etc., may be included.

For the total number of cabin passengers so accommodated below there shall be reserved on deck, or provided on a bridge, deck, or other suitable place, promenade, or airing space at the rate of 3 square feet per passenger, and this space shall not

be counted or included in the area available for deck or any other passengers.

To obtain the number of second-class or steerage passengers, measure the unencumbered floor-space of the dining saloon (if any), and the floor-space of shelters to deck passengers; and divide the number of square feet by three. For compartments neither dining saloons nor deck shelters, the number is that of the fixed beds or sofas therein, but there must be 72 cubic feet for each person. The sofas, etc., in the saloons already measured must not be included in the above number. If there are three classes of passengers, airing space at 3 square feet per person must also be reserved for the second-class passengers.

In general the main deck, the deck beneath, and the raised quarter-deck (if any) may be measured; also the poop or bridge house, promenade deck, etc., over up to one-quarter the length, provided the stability is satisfactory and that there are bulwarks or rails $3\frac{1}{2}$ ft. high (with weather cloths) fitted as specified above.

The main deck should, if necessary, be protected with close bulwarks 4 feet high.

For voyages not exceeding ten hours the whole of the clear upper surface of the promenade deck, poop, etc., may be included.

The number of deck passengers is obtained by dividing the clear area in square feet by nine. In measuring, take the breadths from the point of waterway, rail or covering board which is the most inboard; deduct all incumbrances, sponsons (in paddle steamers) and houses over, areas between rail and deck-house less than 2 ft. 6 in. wide, forecastle deck (for the foremost one-eighth length if joined to deck amidships), lower hold or cargo space, portions of deck overhanging side or occasionally used for navigation, decks carried on stanchions or extensions of frames not plated. In saloon steamers the tops of saloons or bridge decks, if sufficiently strong and not carried on stanchions, may be included. Not more than three decks in all to be measured except in special cases.

The total number of passengers, other than saloon or first-class, must not exceed six times the number (at 9 square feet per person) that can be sheltered.

The total number of passengers must never exceed the gross tonnage of the vessel.

In well-decked vessels, the space between topgallant forecastle and raised quarter-deck, etc., must not be included unless sufficiently high, and having freeing ports on each side with areas from $9\frac{1}{2}$ to $12\frac{1}{2}$ square feet when from 30 to 60 feet long, and 1 square foot extra for each additional 5 feet length of bulwarks.

Cattle on the open deck must be separated from passengers by partitions, not necessarily close, with efficient wash-boards. If under cover they must be separated by a movable close bulkhead from deck to deck. If below, the compartments and their ventilation must be completely separated from those for the passengers. Deduct one passenger for each square yard of passenger space occupied by cattle or cargo.

Passengers in Excursion Steamers.

For steamers used in excursions the rules for calculating the number of passengers are the same as in sea-going home-trade steamers, except that if application is made for an excursion certificate for short distances along the coast during daylight, the number, originally calculated at 9 superficial feet to each passenger, should it exceed the gross tonnage of the vessel, need not be diminished so as to bring it down to that number.

Windows in saloon houses should have efficient portable shutters.

Passengers in Steamers plying in partially smooth water.

The measurements are to be made in the same manner as in home-trade sea-going steamers, except that one saloon only is to be included.

There will be no distinction between fore- and after-cabin passengers.

Divide the number of superficial feet on deck, obtained as before, by six, and the clear space in the saloon by nine,* and the sum of these quotients will be the number of passengers allowed.

In the last-mentioned class of steamers one and a half passengers per square yard of the space measured for passengers which is occupied by cattle, cargo, etc., to be deducted.

Between October 31 and April 1 the number of passengers which, according to the preceding rules, is allowed to be carried other than in cabins or saloons during summer is to be reduced by one-third.

These vessels are to be provided with a suitable anchor and cable, and a compass properly adjusted, and suitable life-saving appliances.

Passengers in Steamers plying in smooth water.

Divide the number of superficial feet on deck, obtained as before, by three,* and the clear space in the saloon or on bridge decks, etc., by nine, and the sum of these quotients is the number of passengers allowed.

* In new vessels the divisor may be nine for small rooms on upper deck up to 90 square feet area, or six up to 270 square feet in smooth water.

Three passengers are to be deducted for every square yard of space measured for passengers occupied by cattle, cargo etc.

No reduction to be made in winter months.

These vessels are to have a suitable anchor and cable.

Open Boats or Launches.

The number of passengers must not exceed the seating accommodation equal to the total length of fixed seats, including thwarts, in feet divided by 1.5. The stability must be tested, unless obviously ample; and, if satisfactory, additional passengers standing may be allowed. The height of gunwale should be in accordance with the table, page 479.

STRENGTH OF BULKHEADS

(*Recommended in the First Report of the Committee on the Subdivision of Ships*).

(*See tables on pp. 484*, 485.)

ATTACHMENTS FOR STIFFENERS (dimensions are in inches).

Type and Depth of Stiffener.	Bracket Attachments.				Lug Attachments.	
	Thickness of Bracket.	Width of Flange.	Rivets in each Arm. No.	Rivets in each Arm. Diam.	Rivets in Lugs. No.	Rivets in Lugs. Diam
Angles up to 6″ . . .	·34	—	3	$\frac{3}{4}$	2	$\frac{3}{4}$
Bulb angles 7″	·44	—	5	$\frac{3}{4}$	3	$\frac{3}{4}$
,, ,, 9″	·44	$2\frac{3}{4}$	7	$\frac{3}{4}$	4	$\frac{3}{4}$
,, ,, 12″	·44	$3\frac{1}{2}$	9	$\frac{7}{8}$	6	$\frac{7}{8}$
Channels 12″ × 3½″ . .	·44	$3\frac{1}{2}$	10	$\frac{7}{8}$	6	$\frac{7}{8}$
,, 15″ × 4″ . .	·50	$4\frac{1}{2}$	14*	$\frac{7}{8}$	8	$\frac{7}{8}$
Plates 15″ with 3″ angles	·50	$4\frac{1}{2}$	16*	$\frac{7}{8}$	8	$\frac{7}{8}$
,, 21″	—	—	—	—	10	$\frac{7}{8}$

Note.—Distance from heel of boundary bar to ends of bracket arms = three times depth of stiffener; if more than 24″, bracket should be flanged. Either bracket or lug attachments in accordance with the table can be used.

THICKNESS OF BULKHEAD PLATING.

D = Depth at middle line from bulkhead deck to lower edge of plate in feet.

t = Thickness in inches.

* In two rows.

SIZES OF STIFFENERS SPACED 30 INCHES AND HAVING BRACKET ATTACHMENTS AT TOP AND BOTTOM.

(All scantlings in inches.)

Length of Stiffener, incl. attachments.	Height of Bulkhead Deck above top of Stiffener.					
	0	8′	16′	24′	32′	40′
ft. 8	A 3½ × 2½ × ·28	A 5½ × 3 × ·32	5½ × 3 × ·30	6 × 3 × ·40	7 × 3 × ·36	7½ × 3 × ·40
12	A 5½ × 3 × ·36	6½ × 3 × ·38	7½ × 3 × ·48	8½ × 3 × ·52	9½ × 3½ × ·52	10½ × 3½ × ·50
16	6½ × 3 × ·38	8½ × 3 × ·48	10 × 3½ × ·52	11½ × 3½ × ·52	12 × 3½ × ·64	12 × 4 × 4 × ·54/·625
20	8½ × 3 × ·46	11 × 3½ × ·50	12 × 3½ × 3½ × ·46/·60	13 × 4 × 4 × ·50/·625	15 × 4 × 4 × ·52/·625	15 × ·42 3 × 3 × ·42
24	10½ × 3½ × ·54	12 × 3½ × 3½ × ·60/·60	14 × 4 × 4 × ·60/·62	15 × ·42 3 × 3 × ·42	15 × ·46 3½ × 3½ × ·46	—

Note.—Stiffeners marked A are angle bars; the remaining ones with three dimensions are angle bulbs. Those with four dimensions are channels, the upper thickness being that of the web, and the lower that of the flange. Those in two lines are plates with double face angles.

SIZES OF STIFFENERS SPACED 30 INCHES AND HAVING LUG ATTACHMENTS AT TOP AND BOTTOM.
(All scantlings in inches.)

Length of Stiffener, incl. attachments.	Height of Bulkhead Deck above top of Stiffener.					
	0	8′	16′	24′	32′	40′
ft. 8	A 4 × 3 × ·34	$5\frac{1}{2}$ × 3 × ·32	$6\frac{1}{2}$ × 3 × ·44	$7\frac{1}{2}$ × 3 × ·46	$8\frac{1}{2}$ × 3 × ·46	9 × 3 × ·52
12	$5\frac{1}{2}$ × 3 × ·38	8 × 3 × ·44	$9\frac{1}{2}$ × $3\frac{1}{2}$ × ·50	11 × $3\frac{1}{2}$ × ·52	12 × $3\frac{1}{2}$ × ·56	12 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·58/·60
16	8 × 3 × ·46	$10\frac{1}{2}$ × $3\frac{1}{2}$ × ·56	12 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·48/·60	13 × 4 × 4 × ·56/·625	15 × 4 × 4 × ·58/·625	15 × ·40 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·40
20	$10\frac{1}{2}$ × $3\frac{1}{2}$ × ·54	12 × 4 × 4 × ·54/·625	15 × 4 × 4 × ·62/·625	$15\frac{1}{2}$ × ·40 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·40	17 × ·44 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·44	19 × ·46 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·46
24	12 × 4 × 4 × ·48/·625	15 × ·40 3 × 3 × ·42	17 × ·42 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·42	$19\frac{1}{2}$ × ·46 $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·46	21 × ·46 4 × 4 × ·46	—

Note.—Stiffeners marked A are angle bars; the remaining ones with three dimensions are angle bulbs. Those with four dimensions are channels, the upper thickness being that of the web and the lower that of the flange. Those in two lines are plates with double face angles.

t	D (stiffeners spaced 30") up to	D (stiffeners spaced 36") up to
·28	12	7
·34	24	17·5
·40	36	28
·46	48	38·5
·52	60	49
·58	—	59·5

General Notes on W.T. Bulkheads, etc.

(*Recommended in the First Report of the Committee on the Subdivision of Ships.*)

The *bulkhead deck* is the uppermost continuous deck to which all transverse bulkheads are carried.

No W.T. compartment shall exceed 92 feet in length nor be regarded as part of the W.T. subdivision (except in the peaks of ships less than 200 feet in length) if less than 10 feet in length.

Side scuttles below a deck which is less than 7 feet above the L.W.L. shall be permanently fixed, except special scuttles provided with metal shutters, and kept closed and locked at sea.

The minimum distance of an inner skin from the outer skin should be 2 feet plus 2 per cent of the moulded beam.

The lowest strake of a bulkhead at the end of a stokehold or bunker space should be 36 in. high and 0.1 in. thicker than given by the table. In other cases the lowest strake should be ·04 in. thicker; limber plates being ·1 in. thicker.

Boundary angles should be ·1 in. thicker than the bulkhead.

The ends of the stiffeners should be connected by either brackets or lugs to efficient horizontal plating; the lower brackets should extend over the adjacent floor (which should be solid); the upper brackets should be connected to angles which extend over the adjacent beam space.

The rivets in seams, end connexions, and boundary bars should be spaced 4½ diameters, except in the shell flange of boundaries where 5 diameter spacing is permissible. The boundaries should be double riveted when more than 24 feet below bulkhead deck; over 35 feet, the vertical butts should also be double riveted. The stiffeners rivets should be spaced 7 diameters, except for 15 per cent of the length at each end, when spacing should be 4 diameters if lug attachments are used. Collision bulkheads should have stiffeners 24 in. apart; but the scantlings should be based on 30 in. spacing.

W.T. decks and trunks should have the same strength as required for bulkheads in the same position.

Bulkheads should be hose-tested at 30 lb./in.^{2} pressure; fore and after peaks, inner skins and double bottoms should be filled with a head up to the bulkhead deck.

The double bottom should extend from machinery space to forepeak bulkhead in ships 200 feet to 250 feet long; outside machinery space to fore and after peaks in ships 250 feet to 300 feet long; also amidships in ships over 300 feet long, when it should extend to the bilges.

Bilge Suction Pipes. — These should have a minimum diameter in inches of $1 + \frac{1}{50}\sqrt{(L \times (B + D))}$ for main suctions, and $1 + \sqrt{(l \times (B + D) \div 1500)}$ for branches to cargo and machinery spaces, where L, B, D are the principal dimensions, and l the length of compartment in feet. In no case should these be less than 2½ in. and 2 in. respectively.

INTERNATIONAL REGULATIONS FOR PREVENTING COLLISIONS AT SEA.

LIGHTS.

To be carried from sunset to sunrise. 'Visible' applies to a dark clear night.

1. (*a*) A steam vessel under way carries on the foremast (or equivalent position), at a height above the hull equal to the breadth of the vessel (but not less than 20 feet or over 40 feet), a white light, visible 5 miles, showing from right ahead to 2 points abaft the beam on each side.

(*b*) Also a green light on the starboard side and a white light on the port side, each visible 2 miles and showing from right ahead to 2 points abaft the beam. A screen projecting at least 3 feet forward to be fitted to prevent these lights from crossing the bow.*

(*c*) A white light may be carried in addition to the first described. Of these, one to be at least 15 feet lower than the other, and at a greater distance before it.

2. A steam vessel towing shall carry two white lights similar to 1 (*a*), at least 6 feet apart in the same vertical. If the length of tow from stern to stern exceed 600 feet, a third light above or below shall be carried. A small white light may be placed aft, but it shall not be visible before the beam.

3. (*a*) A vessel not under control shall carry in lieu of 1 (*a*) two red lights (two 2 feet black balls by day) at least 6 feet apart in the same vertical, and visible 2 miles all round the horizon.

(*b*) A vessel employed on telegraph cable work shall carry in lieu three such lights, 6 feet apart, the central white and the others red. By day three 2 feet shapes, the central diamond and white and the others globular and red.

(*c*) In both the above, the side lights should be carried only when under way.

4. A sailing vessel under way or any vessel that is being towed shall carry the side lights only.

* The edge of the screen should be in a fore and aft line with the inner edge of wick, the athwartship width of which should be—maximum 2″, minimum 1″ (paraffin) or 1½″ (colza).

5. In small vessels under way during bad weather, the side lights need not be fixed, but may be exhibited on approach of other vessels.

6. Steam vessels of gross tonnage less than forty, and sailing or rowing boats less than twenty, need not carry the above lights, but must have in lieu :—

(*a*) *Steam Vessels.*—Nine feet above the gunwale (or less in small steamboats) in front of the funnel a white light according to 1 (*a*), but visible 2 miles. Also green and red sidelights according to 1 (*b*) ; or a combined red and green lantern at least 3 feet below the white light, visible 1 mile.

(*b*) *Vessels under Oars or Sails.*—A portable combined red and green lantern as above. Rowing boats under oars or sail shall have a portable white light.

7. Vessels on pilotage duty shall show only a white all-round masthead light ; together with a flare-up light showing every fifteen minutes or less. The red and green side-lights shall be shown only on the approach of other vessels.

A vessel exclusively employed by licensed pilots shall show her side-lights, and in addition an all-round red light, visible 2 miles, 8 feet below her masthead light. At anchor the side-lights shall be omitted.

8. (*a*) Open boats, when fishing, shall carry one all-round white light ; if outlying tackle extends more than 150 feet horizontally, on approach of other vessels a second white light 3 feet below the first and 5 feet away in the direction of the tackle shall be shown.

(*b*) Vessels, other than open boats, when fishing with drift nets or lines shall carry two white lights visible 3 miles. They shall be from 6 feet to 15 feet apart vertically, and 5 feet to 10 feet horizontally, the lower being in the direction of the nets.

(*c*) Trawlers and vessels with dredge nets, if steam, shall carry in lieu of 1 (*a*) a tricoloured lantern showing white from right ahead to two points on each bow ; also green on starboard side and red on port side to two points abaft the beam ; from 6 to 12 feet below this a white all-round light. If sailing, they shall carry a white all-round light, and also show on approach of other vessels a white flare-up light. All these lights to be visible 2 miles.

(*d*) All fishing vessels or boats when under way shall exhibit the usual lights in lieu of the special ones above described. At anchor the light specified in (10) should be shown, and, in addition, if attached to a net or similar gear, an additional white light as described in 8 (*a*) shall be exhibited on approach of other vessels. They may also use a flare-up light and use working lights as desired. In daytime, all vessels fishing with nets, lines, or trawls shall

display a basket or similar signal whether at anchor or under way.

9. A vessel overtaken by another shall show a white or flare-up light from the stern. If fixed it should be visible 1 mile, showing from right aft through six points on each side, and at about the same level as the side-lights.

10. At anchor or aground a vessel under 150 feet in length shall show a white all-round light visible 1 mile, not higher than 20 feet above the hull. Over 150 feet this light shall be from 20 to 40 feet high, and a similar light shall be placed at the stern at least 15 feet below the forward light.

11. A steam vessel under sail with funnel up shall carry forward in daytime a black ball 2 feet diameter

Fog Signals.

These consist of a whistle or siren in steam vessels, and a mechanical fog-horn in vessels sailing or towed; also a bell in each case. In fog, mist, falling snow, or heavy rainstorms, day or night, the following signals shall be given:—

(*a*) Steam vessel under way—a prolonged blast every two minutes.

(*b*) As above, but stopped—two prolonged blasts every two minutes, with one second interval.

(*c*) Sailing vessel under way—every minute, on starboard tack one blast, on port tack two blasts, with the wind abaft the beam three blasts in succession.

(*d*) A vessel at anchor—every minute, ring bell rapidly during five seconds.

(*e*) A vessel towing or not under command (in lieu of above)—every two minutes sound one prolonged blast, followed by two short blasts.

(*f*) Fishing vessels with lines out—every minute one blast, followed by ringing the bell.

Sailing vessels and boats of less than 20 tons gross tonnage are exempted, but they must make some efficient sound signal every minute.

Steering and Sailing Rules.

1. When two sailing vessels are approaching—

(*a*) The one running free shall give way to the one close-hauled.

(*b*) The one close-hauled on port tack shall give way to the one close-hauled on the starboard tack.

(*c*) If both are free, the one having the wind on the port side shall give way.

(*d*) If both are free, the one which is to windward shall give way to the one which is leeward.

(*e*) One which has the wind aft shall give way to any other.

2. When two steam vessels are meeting nearly end on, each shall alter her course to starboard.

3. When two steam vessels are crossing, the one which has the other on her starboard side shall give way.

4. A steam vessel shall give way to a sailing vessel.

5. Any vessel overtaking another, i.e. coming up from a direction which is at any moment more than two points abaft the beam of the other, shall give way to the other.

6. In narrow channels each vessel shall keep to her starboard side as far as practicable.

7. Sailing vessels shall give way to vessels engaged in fishing.

8. A steam vessel shall indicate her course to another vessel in sight by one short blast with whistle or syren on turning to starboard, two short blasts on turning to port, three short blasts on putting engines astern.

9. A vessel in distress shall signal together or separately as follows :—

By day (*a*) a gun fired every minute, (*b*) the code signal NC, (*c*) a square flag having a ball beneath it, (*d*) a continuous sounding with a fog signal. By night (*a*) and (*d*) as before ; but (*b*) flares on the vessel, (*c*) rockets or shells throwing stars at short intervals.

TONNAGE.

Register Tonnage.

The gross tonnage of a ship expresses her internal cubical capacity in tons of 100 cubic feet each. It is calculated as indicated below ; but the gross under-deck tonnage (i.e. exclusive of that due to erections) may be found approximately by the following formula :—

L = the length at load-line from front of stem to back of sternpost.

B = the breadth extreme to outside of plating.

D = the depth from top of upper deck amidships to top of keel.

$$\text{Gross tonnage under deck} = \frac{L \times B \times D}{100} C.$$

Value of C.

Passenger steamers of high speed and sailing ships	·6 to ·65
Passenger and cargo steamers	·7 to ·72
Cargo steamers and oil-tank steamers	·72 to ·8

To calculate the Gross Tonnage.

The tonnage deck is the upper deck in all vessels under three decks, in all other vessels the second deck from below.

Measurements to be expressed in feet and decimals of a foot.

The length for register tonnage is taken from inside of plank at stem to inside of midship stern timber, or plank there, as the case may be, and is taken on the tonnage deck; the length so taken (having made deductions for the rake of stem and stern, if any, in the thickness of the deck, and one-third of the round of the beam) is to be divided into the prescribed number of equal parts, according to the length, as follows:—

Length.	No. of Intervals.
Not exceeding 50 feet and under	4
Exceeding 50 feet and not exceeding 120 feet .	6
Exceeding 120 feet and not exceeding 180 feet .	8
Exceeding 180 feet and not exceeding 225 feet .	10
Exceeding 225 feet	12

In the case of a break in the double bottom for water ballast, take the length in parts between the breaks, using the above rule.

Transverse sections are then measured at each of the points of division, as follows:—

The total depths of the transverse sections are measured from the under side of the tonnage deck to the upper side of floor timber (or inner bottom plating) at the inside of the limber strake, after deducting average thickness of ceiling and one-third of the round of the beam. The depths so taken are to be divided into five equal parts, if midship depth does not exceed 16 feet; otherwise into seven equal parts.

The breadths are measured horizontally at the points of division, and also at the upper and lower points of each depth, each measurement extending to the average thickness of that part of the ceiling which is between the points of measurement.

The areas of the transverse sections are then computed down to the lowest point of division by Simpson's first rule (p. 44); the area below is then calculated by subdividing the lowest interval into four equal parts and applying the same rule to the additional horizontal breadths thus obtained; the sum of the two parts is the whole area of the section. The capacity of the ship is computed by the same rule (Rule II, p. 54)—that is, the areas are treated as the ordinates of a new curve of the same length as the vessel; and the area of that new curve, found by Simpson's first rule, will be the capacity of the vessel in cubic feet, which being divided by 100 gives the gross tonnage under tonnage deck.

If the ship has a deck or decks above the tonnage deck, the volume of each 'tween deck space is computed by a similar method using the same number of ordinates in the length, the length being measured at mid-height.

In ships where the under-deck tonnage cannot be obtained by direct measurement it should be estimated as follows: Measure extreme length on highest deck, extreme breadth, and corresponding girth from height of upper-deck (as measured by a chain under the keel). Add half the girth to half the breadth; square the sum, and multiply it by the length. The product multiplied by ·0017 (for wood ships) and ·0018 (for iron ships) shall be deemed the tonnage of the ship, subject to the usual deductions and additions.

The capacity of the poop, deck-house, forecastle, break, or any other permanent closed-in space available for cargo or stores, or for the accommodation of passengers and crew, shall be similarly obtained, and included in the gross tonnage. The following spaces, however, are exempted from the above rule: (1) Shelter-deck spaces, with permanent middle-line deck openings at least 4 feet long and of the width of the after cargo hatch, (2) shelters for deck passengers on short voyages, (3) closed-in spaces solely for machinery, (4) wheel-house, (5) cook-house and bakeries, (6) condenser space, (7) w.c.'s for officers and crew.

To calculate the Register or Net Tonnage.

The deductions allowable from the gross tonnage are as follows, no deduction being permitted for any space that has not already been measured and included in the gross tonnage:—

(*a*) Propelling space. This may include spaces actually occupied by engines and boilers and closed-in spaces over for admitting light and air. Also shaft trunks in screw ships. Exclude store-rooms and cabins.

Divide the volume in cubic feet by 100. (1) If in screw steamers this be over 13% and under 20% of the gross tonnage, deduct 32% of the gross tonnage; otherwise deduct tonnage of space multiplied by 1·75. (2) If in paddle steamers this be over 20% and under 30% of the gross tonnage, deduct 37% of the gross tonnage; otherwise deduct tonnage of space multiplied by 1·5. In all new ships, except tugs, the maximum deduction for machinery is limited to 55% of the gross tonnage diminished by the further allowance detailed below (crew space, etc.).

(*b*) Master's and crew's spaces. (In warships only a small proportion of this is deducted.)

(*c*) Spaces for working helm, capstan, anchor gear, or for keeping charts, signals, and other gear for navigation, and boatswain's stores.

(*d*) Space for donkey-engine and boiler, if connected to main pumps.

(*e*) Water ballast space (other than double bottom).

(*f*) Sail-room, limited to 2½% of the gross tonnage, in ships wholly propelled by sails.

Note.—All such spaces must be plainly marked, and exclusively reserved for the object indicated. Double-bottom spaces available for water-ballast only (not for fuel, stores, or cargo) are not included in the gross tonnage, and no deduction is necessary. In open boats the volume is to be measured to the upper edge of the upper strake at each section.

Suez Canal Tonnage.

This is determined in a manner similar to that used for Register Tonnage in Great Britain (see above); but there are the following differences:—

1. All permanently enclosed spaces are included in the gross tonnage. Unenclosed shelters are excluded; also the fore end of the forecastle extended from the stem over a length equal to $\frac{1}{8}$ the length of ship; similarly in the poop from right aft over $\frac{1}{10}$ length of ship; also such length of the bridge as is equal to the length of machinery space deck openings. Shelter-deck space is included, except immediately opposite any openings in the side.

2. For the net tonnage the following deductions are made (maximum 5% of gross tonnage). Spaces (including mess-rooms, cook-houses, bathrooms, and latrines) for ship's officers and crew; spaces for working helm, capstan, and anchor gear, and for keeping gear for navigation. No deduction is made for accommodation wholly or partly for passengers, captain, purser, stewards, etc., or for peak ballast tanks.

In steamships the following additional deductions are made (limited to 50% of the gross tonnage, except in tugs). Spaces occupied by engines, boiler, coal-bunkers, shaft trunks, engine and boiler casings between decks (German rule). For ships with moveable coal-bunkers (or alternatively in any case) the deduction allowed is equal to the machinery space exclusive of bunkers × $1\frac{1}{2}$ in paddle steamers or $1\frac{3}{4}$ in screw steamers. (Danube rule.)

Tonnage and Displacement.

The net tonnage (Suez Canal) of steamers is therefore at least 45% of the gross tonnage, and in high-speed ships is exactly that ratio. The net tonnages under British and Suez Canal rules are now approximately equal. The ratio of the net tonnage to the displacement in tons is approximately: battleships 35%, light and heavy cruisers 30%, destroyers 40%, fast passenger steamers 30%, coasters 25%, sailing ships 40%. The gross tonnage in many vessels is about one-half the load displacement, rather less in large ships.

Panama Canal.

The tonnage for vessels passing through this canal is estimated on a basis generally similar to that for Suez Canal; the following are the principal differences:—

Double-bottom spaces for oil fuel and feed-water are included in the gross tonnage, but deducted for the net tonnage independently of the allowance for propelling power.

Erections are included as in Suez regulations, but the deductions allowed are slightly fewer.

Propelling-power space is allowed for as in Suez regulations. Deductions are allowed for master's and crew's accommodation, navigating spaces, and peak ballast-tanks as in British rules; there is no percentage limitation.

Marking of Ship.

Every British ship to be permanently marked as follows:—

(*a*) Her name on each bow, and her name and port of registry on the stern; letters to be at least 4 inches long, and either light on a dark ground or the converse.

(*b*) Her official number and her registered tonnage to be cut on her main beam.

(*c*) On each side of the stem and stern-post a scale of feet denoting the draught of water. Letters to be 6 inches high, the lower line denoting the draught; to be cut in and painted white or yellow on a dark ground.

Dead-weight Cargoes.

To estimate approximately the dead-weight cargo which a ship can safely carry on an average length of voyage.

Rule.—Deduct the tonnage of the space for passenger accommodation from the net register tonnage, and multiply by the factor given below.

Type of Vessel.	*Factor (Sir W. H. White).*
Iron and steel sailing ships	1·4
Cargo steamers	$1\frac{3}{4}$
Passenger steamers	$1\frac{1}{2}$ down to about 1 (fastest vessels).

Builder's Tonnage, or Old Measurement Tonnage (obsolete).

To compute the Builder's Tonnage.

Rule.—Measure the length of the vessel along the rabbet of the keel from the back of the main stern-post to a perpendicular line let fall from the fore-part of the main stem under the bowsprit; measure also the extreme breadth to the outside planking, exclusive of doubling planks. Three-fifths of that breadth is to be subtracted from the length; the remainder is called the length of keel for tonnage. Multiply the length of keel for tonnage by the breadth, that product by the half-breadth, and divide by 94; the quotient will be the tonnage.

If L = length, B = breadth, then

$$\text{Tonnage (B.O.M.)} = \frac{(L - \frac{3}{5}B) \times B \times \frac{1}{2}B}{94}.$$

Measurement of Yachts for Tonnage.

(For list of measurement formulæ, see paper by Mr. R. E. Froude, Trans. I.N.A., 1906.)

1. *International Conference Rule.*—See p. 520.

2. *New York Yacht Club Rule.*—Rating $= \dfrac{L \times \sqrt{S}}{5 \cdot 5 \sqrt[3]{W}}$

L = mean of lengths on water-plane and over all, both in feet.

S = sail area in square feet.

W = displacement in racing trim measured in cubic feet.

LIFE-SAVING APPLIANCES.

Board of Trade Rules (1914).

Classes.—Ships are divided into 'Foreign-going' and Home-trade (including Channel Islands and as far as Brest and River Elbe). Each is divided into a number of classes.

Foreign-going.

Class I: Passenger Steamers and Emigrant Ships.—Total lifeboat capacity (subject to the alternatives referred to, below, *v.* "*General*") to equal total number of persons carried or certified. The number of davits to be as in A, Table 1, p. 501; but this number need not exceed the number of boats required. Each davit set to have a Class I lifeboat attached, of which at least the number stated in B, Table 1, must be open boats. The remaining boats may be open or pontoon boats of Classes 1 or 2.

Class II: Steamers not Certified for Passengers.—Lifeboats on each side of ship and attached to davits to be sufficient to accommodate all on board; if several boats are required, the excess above two may be of Class 3 in lieu of Classes 1 or 2.

Class III: Sailing Ships with more than Twelve Passengers.—Lifeboats, attached to davits where practicable, to accommodate all on board.

Class IV: Sailing Ships with not more than Twelve Passengers.—Lifeboats of Class 1 to accommodate all on board. If one only is required, a Class 3 boat in addition to be carried; if several, a Class 3 boat can be carried in lieu. Two boats (one on each side) must be attached to davits.

Home Trade.

Class I: Passenger-carrying Steamships.—Number of sets of davits to be as A, Table I, but not more than number of boats required; each to have a lifeboat attached. The number of open boats to be as B, Table 1; the remaining boats may be open or pontoon. In new ships, if total lifeboat capacity is less than the number of persons carried, it must be increased to

that in 1, Table 2, p. 502; any defect then remaining to be made up by approved buoyant apparatus. For daylight voyages, March 20 to September 30, if the ordinary accommodation is allowed to be increased, the total capacity of boats and buoyant apparatus to be at least 80 per cent of the number of persons on board.

Class II : Steamers not carrying Passengers.—If over 100 feet length to carry a boat in davits on each side; one may be Class 3. If 100 feet or less to carry one or more boats of Class 1 which can be readily lowered on either side. In any case total boat capacity available each side should equal number of persons carried.

Class III : Passenger Sailing Ships.—Lifeboats, attached to that in A, Table 2, p. 502; any defect then remaining to be made davits where practicable, to be capable of carrying all on board.

Class IV : Sailing Ships not carrying Passengers.—Lifeboats, capable of being lowered on either side, to accommodate all on board. In ships 100 feet or more in length, one boat to be Class I.

Class V : Passenger Steamers either coastal or plying between Great Britain, Ireland, and Isle of Man.—In general as Class I. In certain daylight voyages between June 1 and August 31, the number of davits and capacity of lifeboats may be in accordance with B and C, Table 2.

Class VI : Passenger Steamers making short Sea Excursions in Daylight between April 1 *and October* 31.—The number of davit sets, each having a Class 1 lifeboat of reasonable capacity to be as D, Table 2; but total boat accommodation need not exceed the number of persons carried. If necessary the total accommodation to be increased by rafts or buoyant apparatus to 70 per cent of the number of persons carried.

Class VII : Passenger Steamers in Partially Smooth Water.—As Class VI, except that total accommodation need not exceed 60 per cent of the number carried.

Class VIII : Passenger Steamers in Smooth Water in Estuaries and Lakes.—If length is 70 or under 150 feet, one boat is required; if 150 feet or over, two boats. These to be carried in davits. If necessary additional buoyant apparatus to bring total accommodation (including that of boats) up to 40 per cent of the number carried is to be provided. These regulations and those for Class IX may be waived in special cases.

Class IX : Passenger Steamers in Smooth Water on Rivers or Canals.—As Class VIII, except that one boat is sufficient for any length over 70 feet.

Class X : Steam Launches, and Motor-boats making Short Sea Trips.—If over 60 feet in length, as Class VIII.

Class XI : Sailing Boats making short Sea Trips with more than Twelve Passengers.—If over 60 feet in length, as Class III.

Class XII: Tugs, Dredgers, Barges, etc., which proceed to Sea.—As Class II.

Class XIII: Vessels as Class XII which do not proceed to Sea.—To carry a boat to accommodate all on board.

Supply of Life-buoys and Life-jackets.

The number of life-buoys to be as follows:—

Class of Ship.	No. of Buoys.	Class of Ship.	No. of Buoys.
Foreign, I (under 400′ length)	12	Home, I, V	10
Foreign, I (under 600′ length)	18	,, II, IV, XII (100′ and over)	4
Foreign, I (under 800′ length)	24	,, II, IV, XII (under 100′)	2
Foreign, I (above do.)	30	,, III, IX	4
,, II . .	6	,, VI, VII (200′ and over)	8
,, III . .	6	,, VI, VII (under 200′)	4
,, IV . .	4	,, VIII (150′ and over)	6
		,, VIII (under 150′)	4
		,, X and XI (60′ and under), XIII	2
		,, X and XI (over 60′)	4

One life-jacket is to be carried per person in all cases; and in addition a sufficient number suitable for children in Classes I and III foreign, and I, III, V, VI, VII, X, XI, home.

General.

Children under one year are not included in the number of persons carried; two children under 12 count as one person. Daylight extends from one hour before sunrise to one hour after sunset.

Buoyant apparatus or other approved appliances may be accepted in lieu of lifeboats, except that in foreign-going passenger steamers the total lifeboat capacity shall be at least as C, Table 1, and at least 75 per cent of the total number of persons on board.

The weight of an adult person including life-jacket is assumed to be 165 lb.

Ships carrying twelve passengers or less, and otherwise suitable for Class II, foreign-going or home trade, shall be subject to these rules respectively.

Boats.

Class 1.—A. Open lifeboats with internal buoyancy. The buoyancy to be provided by W.T. air cases, whose volume is one-tenth the cubic capacity of boat; in metal boats capacity to be increased so that buoyancy equals that of a wood boat.

B. Open lifeboats with internal and external buoyancy. The capacity of internal air cases to be 7½ % that of boat (with an addition as above in metal boats). External buoyancy, if of cork, to be 3·3 % of the boat capacity; if of other material to be equivalent as regards buoyancy and stability.

C. Pontoon lifeboats with well deck and fixed W.T. bulkheads. Area of well deck to be 30 % deck area. Height of well deck above water to be ½ % length of boat minimum, increasing to 1½ % length at ends of the well. Reserve buoyancy of boat to be 35 %.

Class 2.—A. Open lifeboats having upper part of sides collapsible. To have internal buoyancy of W.T. air cases and external buoyancy of cork, having capacities in cubic feet per person of 1·5 and 0·2 respectively. The minimum freeboard when loaded in fresh water measured to top of solid hull is to be 8 inches for a length of boat of 26 feet, 9 inches for 28 feet, 10 inches for 30 feet, and so intermediately.

B. Pontoon lifeboats with well deck and collapsible bulwarks. As 1 C.

C. Pontoon lifeboats with flush deck and collapsible bulwarks. The minimum loaded freeboard in fresh water depends on the depth amidships; both are measured from top of deck at side, and the latter down to underside of garboard strake. The tabular freeboard applies to a mean sheer of 3 % length; for boats with a smaller sheer, add to the freeboard one-seventh of the difference between the actual and tabular mean sheers. For intermediate depths freeboard should be interpolated.

Depth in inches . .	12	18	24	30
Freeboard in inches .	2¾	3¾	5⅛	6½

Class 3.—Open boats without internal or external buoyancy.

Motor-boats.—One of nine or less, or two of ten or more, lifeboats may be a motor-boat; in certain cases a greater number may be permitted. These must comply with the requirements of Class 1 lifeboats and be kept well provided with fuel; in fixing the buoyancy the extra weight of motor, etc., must be allowed for.

Construction of Boats.—Boats to be amply stable and strong; in new foreign-going ships they must be capable

of being lowered with full complement and equipment. Thwarts and seats to be low, and bottom boards not more than 2 ft. 9 in. below them. Internal buoyancy chambers to be of copper or yellow metal at least 18 oz. per square feet; to be placed at sides or ends, but not at bottom. External buoyancy to be provided by solid material. The mean sheer of Class 1 open lifeboats to be 4% or more of the length.

Pontoon lifeboats, if wood, to have two thicknesses separated by textile material in bottom and deck; if metal, to have W.T. compartments with access and means of pumping. To test the means of clearing water from the deck, boat to be loaded with weight of iron equal to complement and equipment; the time for clearing two tons of water to vary directly as the length, and in a 28-foot boat to be 60 seconds for Classes 1 C and 2 B, and 20 seconds for Class 2 C.

The buoyancy must not depend on the adjustment of any principal part of the hull. All boats to be fitted to use a steering oar; and to be marked with their dimensions and complement.

Complement of Boats.—Provided the freeboard is satisfactory, and that the number of persons can be carried without inconvenience to the oarsmen, the complement is derived from either the cubic capacity or the surface of the boat as follows:—

Classes 1 A and 3, divide capacity by 10 cubic feet; Class 1 B, divide by 9 cubic feet; Classes 2 A and 2 C, divide surface by $3\frac{1}{2}$ square feet; Classes 1 C and 2 B, divide surface by $3\frac{1}{4}$ square feet (or exceptionally 3 when seating accommodation permits). In all cases the capacity must be at least 125 cubic feet.

The complement may be limited in either very fine-ended or very full boats.

Cubic Capacity.—This is obtained by obtaining the sectional areas inside planking and up to level of gunwale. The volume and the areas are both obtained by Simpson's first rule (p. 43), using four intervals. Certain corrections are introduced (*a*) for excessive sheer, (*b*) if depth amidships is more than 45 per cent the breadth or more than 4 feet. Alternatively capacity may be taken as $\cdot 6 \times$ length $\times$ breadth (external) $\times$ internal depth. The depth taken must not exceed $\cdot 45$ breadth. In a motor-boat deduct space occupied by motor, etc.

Surface.—This is measured outside the planking by taking the horizontal breadths at amidships and at $\frac{1}{4}l$ and $\frac{3}{8}l$ (l = length outside) from amidships. If these breadths are (in order, starting from one end) a, b, c, d, e, then area of surface $= \frac{l}{12}(2a + 1\cdot 5b + 4c + 1\cdot 5d + 2e)$. This is applicable to pontoon boats and Class 2 open boats.

Life-rafts.

To be reversible and fitted with bulwarks on both sides. To be capable of being easily handled without mechanical appliances. To have 3 cubic feet of air cases for each person. To have 4 square feet deck area for each person; deck when loaded to be 6 in. above water.

Stowage.

Lifeboats may be placed in tiers or inside one another, provided they can be readily lowered. Supports to be provided between two boats stowed together. All gear to be readily available in an emergency.

Appliances for Lowering.

Davits are not to be fitted at bows or too near propellers. In new foreign-going passenger steamers the boats must be lowered safely with full complement when there is a list of 15°; gear capable of turning out davits against this list to be provided. Life-lines to be fitted to davit spans; these and the falls to be long enough for use when vessel is light. The boats to be capable of being speedily detached from the falls; those under davits to be ready for service.

Equipment.

Boats.—To consist of oars (two spare and one steering), plugs, thole-pins, sea-anchor, bailer and bucket, rudder and tiller or yoke, painter, boat-hook, fresh-water keg and dipper (one quart for each person), two hatchets, a line becketted outside the boat, and lantern to burn eight hours.

Boats for foreign-going ships and I to V home, also to have in general—mast, sail, and gear (not home trade, nor motor-boats), compass, air-tight case (foreign-going only) with 2 lb. biscuit per person, one gallon oil, and one dozen red lights and box of matches in W.T. tin.

Life-rafts.—In foreign-going ships to carry four oars, steering oar, sea-anchor and painter, fresh-water keg as above, line becketted outside, life-buoy light, one gallon oil, biscuits, and lights as above.

Buoyant Apparatus.—The number of persons supported is taken as $\frac{1}{32}$ part of the number of pounds of iron supported in fresh water.

Life-jackets.—To be capable of floating twenty-four hours in fresh water, with 15 lb. of iron suspended from it. The buoyancy must not depend on air compartments.

Life-buoys.—To be of solid cork or equivalent material, and to support 32 lb. of iron twenty-four hours in fresh water. To be fitted with beckets. One buoy on each side to have a life-line 15 fathoms long. Half (at least six in passenger steamers) to be fitted with self-igniting lights.

TABLE I.

Particulars regarding Class I (Foreign) and Classes I and V (Home).			
Registered Length of the Ship.	(A) Minimum number of sets of davits.	(B) Minimum number of open boats, Class I.	(C) Minimum aggregate cubic capacity of lifeboats in feet (Foreign only).
Feet. Under 120 . .	2	2	980
" 140 . .	2	2	1,220
" 160 . .	2	2	1,550
" 175 . .	3	3	1,880
" 190 . .	3	3	2,390
" 205 . .	4	4	2,740
" 220 . .	4	4	3,330
" 230 . .	5	4	3,900
" 245 . .	5	4	4,560
" 255 . .	6	5	5,100
" 270 . .	6	5	5,640
" 285 . .	7	5	6,190
" 300 . .	7	5	6,930
" 315 . .	8	6	7,550
" 330 . .	8	6	8,290
" 350 . .	9	7	9,000
" 370 . .	9	7	9,630
" 390 . .	10	7	10,650
" 410 . .	10	7	11,700
" 435 . .	12	9	13,060
" 460 . .	12	9	14,430
" 490 . .	14	10	15,920
" 520 . .	14	10	17,310
" 550 . .	16	12	18,720
" 580 . .	16	12	20,350
" 610 . .	18	13	21,900
" 640 . .	18	13	23,700
" 670 . .	20	14	25,350
" 700 . .	20	14	27,050
" 730 . .	22	15	28,560
" 760 . .	22	15	30,180
" 790 . .	24	17	32,100
" 820 . .	24	17	34,350
" 855 . .	26	18	36,450
" 890 . .	26	18	38,750
" 925 . .	28	19	41,000
" 960 . .	28	19	43,880
" 995 . .	30	20	46,350
" 1,030 . .	30	20	48,750

TABLE II.

PARTICULARS REGARDING HOME TRADE SHIPS OF VARIOUS CLASSES.

Length of vessel in feet.	Aggregate lifeboat capacity in cubic feet in ships launched after March 1, 1913.		Number of sets of davits.	
	(A) Classes I and V.	(B) Class V (daylight excursions).	(C) Class V (daylight excursions).	(D) Classes VI and VII.
Under 120	400	300	2	2
„ 140	600	400	2	2
„ 160	850	500	2	2
„ 180[1]	1,150	600	2	2
„ 195[1]	1,300	700	3	2 (under 200′)
„ 210[1]	1,450	800	3	3
„ 225[1]	1,600	950	4	3
„ 240[2]	1,850	1,080	4	3
„ 255	—	1,250	5	4
„ 270	2,350	1,450	5	4
„ 285	—	1,700	6	4 (under 280′)
„ 300	3,000	1,900	6	5
„ 330	3,750	2,150	7	5 (under 320′)
„ 360	—	2,400	8	
„ 370	4,400			
„ 410	5,100	as required	as required	as required
„ 460	6,000			

BOARD OF TRADE REGULATIONS FOR EMIGRANT SHIPS.

(For regulations concerning Ventilation see p. 400.)

An 'emigrant ship' is one which carries from the British Isles to any port outside Europe and the Mediterranean Sea more than fifty steerage passengers, or a greater proportion of them than one adult to every 33 tons of the registered tonnage of a sailing ship, or of every 20 tons for a steamship. An adult is a person of 12 years or more; two younger children are counted as one adult. 'Passenger' refers to 'steerage passenger'[3] in the regulations below, which apply only to steerage accommodation.

[1] Up to 5 feet less for column A. [2] Up to 5 feet more for column A.
[3] *i.e.* other than cabin passengers who must each have at least 36 sq. ft. for their exclusive use.

Emigrant ships are subject to the surveys usual to passenger steamers; and in addition to the following regulations:—

Decks.—If of wood to be properly fastened and caulked. If of steel to be sheathed with wood or approved composition. Height between decks in steerage compartments to be at least 6 feet.

Rails.—To be not more than 6 inches apart between centres unless fitted with netting.

Berths.—Two tiers only to be fitted on one deck. The lower to be at least 12 inches clear above the deck; the interval between each tier and between the upper tier and deck to be at least 2 ft. 6 in.

Each berth to be at least 6 feet long and 1 ft. 10 in. broad (for adults). To be sufficient in number for all passengers. To be separated by gas-tight partitions from w.c.'s and urinals.

All male adult passengers to be separated by substantial bulkheads from all other passengers. Not more than one adult passenger, except husband and wife or females, to occupy the same berth.

Doors.—To be equal in width to the ladders or stairways to which they give access.

Over each hatchway a booby hatch admitting light and air but affording protection from the wet to be placed.

Short passages between cabins to be as wide as the bunks.

Stairways.—The 'weather deck' is the highest complete deck, except in compartments whose only egress is on the deck of a poop, bridge, forecastle, etc.—in which case the deck over is termed the weather-deck.

Separate stairways to be provided to each passage compartment; their aggregate width being at least 2 inches for every five adults accommodated. In stairways for access to weather decks from two compartments take the total accommodation in both for applying this rule; for three compartments take the accommodation of the two largest added to one-half that for the third.

When the stairways leading to weather-deck are enclosed by a poop, bridge, or similar space, the width of the doors in the end bulkheads plus that of the stairways leading to the weather-deck from poop, etc., is to comply with the rule.

The stairways should lead to a weather-deck space always accessible to steerage passengers. No ladder or stairways to be less than 30 inches wide; if more than 50 inches wide intermediate rails to be fitted from 30 inches to 50 inches apart. The width is always the inside clear width on treads or between rails.

There must be 6 feet clear space vertically above each stair. All stairways to have efficient handrails, not ropes,

on each side. To be well lighted by day and night. Ladders to be generally pitched fore and aft; angle to vertical about 37°; those for women to be lined on the back. Those passing through an open sleeping space to be enclosed by close boarding.

Lighting.—Good natural lighting to be provided in all steerage spaces. Side-lights to be at least 9 inches diameter; to have brass or gun-metal frames, and to be fitted with dead-lights. When electricity is the sole means of lighting, the generators must be situated well above the water-line.

Water-closets.—Four to every 100 passengers up to 300, and two for each additional 100 to be provided. To be placed on a passenger deck other than the lowest. Separate closets to be apportioned to, and marked for, males and females. Two additional urinals (or tip-up w.c.'s) to be provided for every hundred male passengers up to 300, and one for each additional hundred.

Hospitals.—Space at the rate of 18 square feet clear for every fifty passengers to be divided off for hospital accommodation. Hospital space to be at least 100 square feet; and one hospital to be set apart for infectious diseases.

They should not contain more fitted beds than one to each 15 square feet; one lying-in or double berth to be provided.

Dispensary.—A separate dispensary is desirable on emigrant ships.

Number of Passengers.—None to be carried on more than one deck below the statutory load-line. This is termed 'the lowest passenger deck'; 'passenger deck' includes every deck above this which is appropriated to passengers.

The lowest passenger deck to be efficiently lighted by side scuttles or otherwise. The number of passengers carried on it is not to exceed one adult to every 18 square feet clear appropriated. If the 'tween deck height is less than 7 feet, or if the apertures, other than side scuttles, for light and air are less than 3 square feet to every 100 passengers, the number is limited to one adult to every 25 square feet.

On a passenger deck the number is limited to one adult for every 15 square feet clear appropriated; 18 square feet are necessary if 'tween deck height is less than 7 feet.

In addition, promenade space, not otherwise reserved, to be provided on a deck so open as not to be included in the tonnage, at the rate of 5 square feet to each adult.

In measuring the passenger and lowest passenger decks, passengers' light luggage space, and that occupied by public rooms, lavatories, and bathrooms exclusively reserved for the steerage may be included; hospital space to be excluded. When separate mess-rooms are provided, the sleeping space appropriated per passenger to be at least 15 square feet on the lowest passenger deck and 12 square feet on passenger

decks. Hatchways below masts, ventilators, and other obstructions to be deducted.

Water.—Four quarts daily for each adult, plus 10 gallons a day for each 100 adults for cooking purposes (exclusive of that for cabin passengers and crew). Where efficient distilling apparatus is fitted, only one-half the normal quantity for the voyage need be carried. If carried in double bottoms it must be distributed in four compartments.

Provisions.—Weekly scale per adult : beef or pork, 36 oz.; preserved meat, 16 ; suet, 6 ; butter, 4 ; bread or biscuit, 40; wheaten flour, 56 ; oatmeal, rice, and peas (any two), 32 ; potatoes, 32; raisins, 6; tea, 2; sugar, 16; salt, 2; mustard, ½; pepper, ¼ ; dried vegetables, 8 oz. ; 1 gill of vinegar. Total weight, 16 lb. 6 oz.

Certain substitutes are allowable, including : 8 oz. fresh or tinned vegetables in lieu of 1 oz. dried vegetables ; 1½ lb. fresh meat = 1 lb. salt meat = ¾ lb. preserved meat ; ¼ oz. tea = ½ oz. coffee or cocoa ; 1 lb. flour = 1 lb. biscuit = 1 lb. rice ; ½ lb. butter = 1 lb. jam or marmalade.

Cargo.—Not to be dangerous to health or lives of passengers, or to safety of ship. Iron or steel rails, or similar dead-weight cargo should not exceed one-third dead-weight capacity of ship.

Cattle.—Not more than twelve dogs and no pigs or male goats to be carried without special permission. 'Cattle' includes deer, horses, and asses ; four sheep or female goats are equivalent to one head of cattle. Not more than one head of cattle to be carried for every 200 tons gross tonnage ; not more than ten head in all. No cattle to be carried below, or immediately above, any deck or in any compartment in which emigrants are berthed ; when in adjoining compartments an efficient iron or steel bulkhead lined with wood or felt on the passenger side to be fitted. Cattle carried on the weather deck used as a promenade space shall be separated by a deckhouse or bulkhead from the passengers ; promenade space within 50 feet of the cattle to be reckoned at 8 square feet per adult.

Miscellaneous.—The above regulations also apply to ships bringing steerage passengers to the British Isles from any port out of Europe and the Mediterranean Sea.

LLOYD'S RULES FOR DETERMINING SIZES OF SHAFTS.

For compound engines with two cranks at right angles—

Diameter of intermediate shaft in inches

$$= (\cdot 04\text{A} + \cdot 006\text{D} + \cdot 02\text{S}) \times \sqrt[3]{\text{P}}.$$

For triple expansion engines with 3 cranks at equal angles—
Diameter of intermediate shaft in inches

$$= (\cdot 038\text{A} + \cdot 009\text{B} + \cdot 002\text{D} + \cdot 0165\text{S}) \times \sqrt[3]{\text{P}}.$$

For quadruple expansion engines with 2 cranks at right angles—

Diameter of intermediate shaft in inches

$$= (\cdot 034\text{A} + \cdot 011\text{B} + \cdot 004\text{C} + \cdot 0014\text{D} + \cdot 016\text{S}) \times \sqrt[3]{\text{P}}.$$

For quadruple expansion engines with 3 cranks—
Diameter of intermediate shaft in inches

$$= (\cdot 028\text{A} + \cdot 014\text{B} + \cdot 006\text{C} + \cdot 0017\text{D} + \cdot 015\text{S}) \times \sqrt[3]{\text{P}}.$$

For quadruple expansion engines with 4 cranks—
Diameter of intermediate shaft in inches

$$= (\cdot 033\text{A} + \cdot 01\text{B} + \cdot 004\text{C} + \cdot 0013\text{D} + \cdot 0155\text{S}) \times \sqrt[3]{\text{P}}.$$

where A = diameter of high pressure cylinder in inches.
B = diameter of first intermediate cylinder in inches.
C = diameter of second intermediate cylinder in inches.
D = diameter of low pressure cylinder in inches.
S = stroke of pistons in inches.
P = boiler pressure above atmosphere in lbs. per sq. inch.

The diameter of crank shafts to be at least $\frac{21}{20}$ths of that of the intermediate shaft.

The diameter of the screw shaft is—

$\cdot 63\text{T} + \cdot 03\text{P}$, but is in no case to be less than $1 \cdot 07\text{T}$

where P is the diameter of the propeller, and
T the diameter of the intermediate shaft, both in inches.

LLOYD'S RULES FOR SHIPS.

Tests of Materials.—See p. 284.

Numbers and Tables.—Length (L) is measured from fore-part of stem to after-part of stern-post on the range of the upper deck beams (second deck in awning and shelter deck vessels).

Breadth (B) is the greatest moulded breadth of the vessel.

Depth (D) is that at middle of length from top of keel to top of beam at side of uppermost continuous deck. In awning and shelter deck ships to the second deck or to 8 feet below the awning or shelter deck, whichever is the greater.

Depth (d) is that at the middle of length from top of ordinary floor at centre (or of double bottom at side) to top of the lowest tier of beams at side, whether widely spaced or not.

B + D is called the transverse number; with 'd' it regulates the dimensions of frames, floors, and web frames.

L × (B + D) is called the longitudinal number and regulates the scantlings of structure contributing to longitudinal strength.

Note.—When obtaining the proportion of length to depth for scantlings of topsides, the depth is to be taken to the highest continuous deck, whether upper, awning, shelter, or long bridge.

Except when otherwise stated, the scantlings in the tables are those amidships, and can be reduced at the ends.

Keel, Stem, Stern-post, Keelsons, and Stringers.—See tables. When breadth is under 27 feet, one side keelson is to be fitted on each side; up to 50 feet, two side keelsons; up to 54 feet, two side and one bilge keelson. All keelsons and stringers to be well butted, the straps to the angles being 2 feet long. Keelsons should preferably be continuous through bulkheads.

Frames, Reverses, and Floors. See tables. The spacing should never exceed 24 inches in the peaks, and 27 inches for one-fifth length abaft collision bulkhead. The height to which the reverses are carried depends on 'd'; if this be from 7 to 9 feet they should terminate at bilge; if from 13 to 27 feet at upper deck, and so intermediately, for a single tier of beams. With more than one tier the reverses should extend to upper deck and deck below alternately.

The depth of floors should be, at three-quarters the half-breadth, at least one-half that at the middle line; they should be carried up the side to a height above top of keel equal to at least twice the midship depth. They should be ·04 and ·10 in. thicker respectively in the engine and boiler spaces.

Web Frames.—To avoid excessive frame dimensions, web frames, six frame spaces apart, of the sizes given in the table, with light intermediate frames may be adopted. Special side stringers, not more than 8 feet from each other or from deck or

top of floor, of the depth of the web frames are to be fitted. When using the table, '*d*' is here taken up to the lowest laid deck. The frames above the lowest deck to be of the sizes of the intermediate frames.

Double Bottom.—This may be fitted in lieu of ordinary frames (see tables). The margin plate is continuous, and the transverse frames also continuous from centre to margin plate. The floors may be fitted at every frame, or at every other frame; the intermediate frames in the latter case consist of the top and bottom girders, vertical stiffeners to the side girders, and plate brackets at centre and against margin plate. Brackets outside the margin plate at each frame extend to a height above top of margin plate of 2″ for longitudinal number 7,500, 20″ for 20,000, and 39″ for 80,000, and so intermediately. The thickness of the central girder is increased about ·10″ to ·04″ in boiler rooms.

The number of side girders is as follows, taking the alternative giving the greater number:—

Floors at every Frame.			Floors at alternate Frames.		
Breadth of Ship.	Breadth of Inner Bottom Amidships.	No. of Side Girders, excluding Middle Line and Margin Plate.	Breadth of Ship.	Breadth of Inner Bottom Amidships.	No. of Side Girders, excluding Middle Line and Margin Plate.
Under 50′	Under 36′	1	Under 34′	Under 28′	1
50′ to 62′	36′ to 48′	2	34′ to 50′	28′ to 36′	2
62′ to 74′	48′ to 60′	3	—	—	
74′ to 86′	60′ to 72′	4	—	—	

Bulkheads.—See table. Steamers are to have the four W.T. bulkheads demanded by the Board of Trade (see p. 473); in addition up to 335 feet in length, another to be fitted in the forehold; up to 405 feet, another in the afterhold; up to 470 feet, seven in all; up to 540 feet, eight in all; up to 610 feet, nine in all; up to 680 feet, ten in all.

Beams.—See table. The round up in all weather decks, except where the longitudinal number is greater than 30,000, and half the deck is covered by erections, should be ¼ inch per foot of beam. They should be fitted at every frame (*a*) at all W.T. flats, (*b*) at upper decks of single deck vessels exceeding 15 feet in depth, (*c*) at unsheathed upper awning, shelter, or bridge decks, and at all such decks in vessels over 450 feet long. Elsewhere, when frame spacing is 27 inches or less, they may be fitted at alternate frames. The knees to be from 2½ to 3 times the specified depth of beam with one row of pillars. The depth across the throat is to be ·6 times that of the knee. In upper decks of large

vessels to be brackets varying from 33″ × 33″ × ·50″ when d is 24′, to 42″ × 42″ × ·54″ when d is 27′. The rivets to vary from 4 – ¾″ when knee depth is 17″ to 9 – ⅞″ when it is 36″. All web frames to have bracket knees of the same thickness and depth as the frame; these are double riveted in each arm.

Pillars.—One row when beam is less than 44′, two up to 60′, and three above. When widely spaced they should be in accordance with the tables where S is their longitudinal spacing, B is ⅓ breadth of ship with two rows and ¼ breadth with three rows, H is the sum of the heights of the several 'tween decks *above* the pillars with an addition of five for the top deck, all in feet. A 'tween deck exclusively appropriated to passengers need count only as 5 feet. Longitudinal girders in accordance with the table are also to be fitted. Alternative forms of pillars and girders of equivalent strength may be used.

Plating. See table. Full thickness to be maintained for ½ length. The butts of adjoining strakes to be two frame spaces apart; those of alternate strakes to be shifted one frame space. Unless special arrangements of butt riveting be devised, the breadth of strakes should not exceed that given below:—

Moulded depth D in feet	under 20	20–24	24–28	28 and above.
Breadth in inches .	54	60	66	72

The thickness of bottom covered by a double bottom with a floor plate at every frame may be reduced by ·02″ if ·52″, by ·04″ if from ·54″ to ·64″, and by ·02″ if ·66″. In way of W.T. bulkheads, wide or diamond-shaped liners extending from frame before to frame abaft bulkhead are to be fitted to the outer strakes.

Decks.—See tables. Pitchpine planks for weather decks to be four to six months old, and the breadth of plank should be 5″ or less. The margin planks of weather decks should be of teak or greenheart. A single nut and screw bolt per beam is sufficient up to 6″ width of plank; from 6″ to 8″, a bolt and one short screw bolt; above 8″ two nut and screw bolts. Bolts to be ½″ diameter up to 3½″ pine or 2¾″ teak, and ⅝″ for greater thicknesses. If a wood flat be laid for a steel top deck, its thickness should be 3″ if pine, 2½″ if teak, or more; for the second deck it should be 2½″. Steel decks are to be caulked unless sheathed with a caulked wood deck.

Riveting.—See pp. 289–92.

Steering Chains.—If D be diameter of rudder head, R radius of quadrant or length of tiller, d diameter of steering chain, all in inches $d = ·38\sqrt{(D^3/R)}$. The diameters of the leading block sheaves should be at least $16d$, and the pins of the sheaves $2d$.

Deck Coamings.—The minimum height of these above *weather* decks should be 18″ on awning, shelter, or bridge decks, 24″ on upper or raised quarter decks, 30″ on upper decks in wells or under tonnage openings of shelter decks.

KEEL, STEM, STERN-POST,
(All dimensions

Longitudinal Number L × (B + D).	Keels. (For flat keels see with bottom plating.)	Stems.	Stern-post without Apertures.	Stern Frames with Apertures.		Keelson Angles.
				Propeller Post.	Rudder Post.	
2,500	6 × 1 1/8	5 1/4 × 1 1/8	5 1/4 × 1 1/8	5 1/4 × 2 1/4	5 × 2 1/4	3 × 3 × ·26
7,000	7 1/4 × 1 7/8	6 1/4 × 1 3/4	6 1/4 × 1 7/8	6 1/4 × 4	5 3/4 × 4	3 1/2 × 3 × ·32
11,500	8 × 2 3/8	7 × 2 1/8	7 × 2 3/8	7 × 5	6 1/4 × 5	4 1/2 × 3 1/2 × ·36
18,000	10 × 2 5/8	9 × 2 3/8	9 × 2 5/8	9 × 5 1/2	8 × 5 1/2	6 × 3 1/2 × ·44
36,000	12 × 3	10 1/2 × 2 3/4	10 1/2 × 3 1/8	10 1/2 × 8	9 × 8	7 × 3 1/2 × ·50
80,000	—	12 × 3 1/2	12 × 4	12 1/2 × 11	11 × 11	—

OUTSIDE PLATING, LOWER
(All dimensions, except

Longitudinal Number L × (B + D).	Outside Plating.					2nd Deck; Upper Deck in Awning and Shelter Deck Vessels.	
	Breadth, Flat Keel and Garboard Strakes.	Thickness, Flat Keel Plate.	Thickness, Garboard Strake with bar keel.	Thickness, Outside Plating: Below upper turn bilge.	Thickness, Outside Plating: From sheer-strake to bilge	Stringer.	Tie plates (T) or Deck Plating (D).
2,600	32	·42	·32	·26	·26	—	—
7,000	38	·56	·44	·38	·36	—	—
11,500	41	·68	·50	·46	·46	41 × ·36	10 × ·36T
18,000	43	·80	·56	·52	·52	43 × ·40	12 × ·40T
36,000	48	1·04	·70	·66	·64	48 ·48	·38D
80,000	58	2·12	—	·98	·90	58 ·62	·56D

KEELSONS, AND STRINGERS.
in inches.)

Middle Line Centre through plate keelson. (B = double bulb angles; P = plate, 4 angles, and rider.)		Flat Keel Plate Angles.	Side Keelsons. (B = double bulb angles; P = plate, 4 angles, and rider.)		Side Stringers. One each side when *d* is less than 14; two from 14 to 21; three when greater than 21.	
Double Angles.	Thickness Centre Plate.		Double Angles.	Intercostal Plates.	Angles.	Intercostal Plates.
3 × 3 × ·26	·30	3 × 3 × ·26	3 × 3 × ·26	·26	3 × 3 × ·26	·24
3½ × 3 × ·32	·34	3½ × 3½ × ·34	3½ × 3 × ·32	·30	3½ × 3 × ·32	·32
6 × 3 × .40B	·40	3½ × 3½ × .48	4½ × 3½ × .36	·36	4½ × 3½ × .36	·36
11 P	·46	4 × 4 × ·52	7 × 3½ × ·42B	·40	6 × 3½ × ·44	·40
18 P	·52	4½ × 4½ × ·60	18 × .64P	·44	7 × 3½ × ·50	·44
—	—	—	—	—	8 × 4 × ·66	·50

DECKS, AND SHORT BRIDGES.
lengths of bridges, in inches.)

3rd Deck; 2nd Deck in Awning and Shelter Deck Vessels.		Decks below the preceding.		'Short' Bridges.			
Stringer.	Tie plates (T) or Deck Plating (D).	Stringer.	Tie plates (T) or Deck Plating (D).	Maximum Length, feet.	Side Plating.	Stringer Plate.	Tie Plates (T) or Deck Plating (D).
—	—	—	—	25	·22	19 × ·22	6 × ·22T
—	—	—	—	45	·26	30 × ·26	7 × ·26T
—	—	—	—	55	·30	37 × ·30	7 × ·30T
13 × ·38	12 × ·38T	—	—	65	·36	42 × ·36	8 × ·36T
18 × ·44	16 × ·44T	—	—	85	·42	40 × ·42	·30D
58 × ·54	·44D	58 × ·54	27 × ·52T	105	·52	51 × ·52	·46D

FLOORS, FRAMES,

Number, B + D.	Frame Spacing in inches.	Floors.			Frames with single reverses.				Frames formed or channels	
		Depth at centre in inches.	Thickness in inches.		All dimensions in inches. The three sizes given are— (a) that of frame, (b) that of reverse, (c) depth of framing.				A signifies a single angle bar. B signifies a single angle bulb. C signifies a single channel bar. B and C together are alternate, according to choice.	
			For ⅗ length.	At ends.	d=8	=15	= 21	= 27	d=9	=15
24	20	8½	·22	·22	2½ × 2½ × ·22 2½ × 2½ × ·22 2½	—	—	—	3½ × 3½ × ·26 A	
40	22	14½	·32	·28	3 × 3 × ·28 2½ × 2½ × ·28 3	4 × 3 × ·30 3 × 3 × ·30 4	—	—	4½ × 3 × ·34 A	5 × 3 × ·36 B
62	23½	26	·42	·36	4½ × 3 × ·32 3½ × 3 × ·32 5	4½ × 3 × ·38 5 × 3 × ·38 6½	5½ × 3 × ·44 6½ × 3 × ·44 8	—	6 × 3 × ·38 B	7½ × 3 × ·44 B
80	25½	32	·48	38	6 × 3½ × ·38 3½ × 3½ × ·38 6½	6 × 3½ × ·44 5 × 3½ × ·44 8	6½ × 3½ × ·48 6½ × 3½ × ·48 9½	8 × 3½ × ·56 8 × 4 × ·56 12½	7½ × 3½ × ·44 B	8 × 3½ × ·44C 9 × 3½ × ·50B
104	29½	—	—	—	6½ × 3½ × ·48 8 × 3½ × ·48 11	7 × 3½ × ·52 8 × 4 × ·52 11½	—	—	11 × 3½ × ·48C 11 × 3½ × ·58B	9 × 3½ × ·46C 3½ × 3½ × ·46B
128	33	—	—	—	—	—	—	—	11 × 4 × ·54C 4 × 4 × ·54B	—

...and Web Frames.

...of single bars and reverses.		Web Frames. Intermediate Frames, and Stringers.									Face Angles (inches).	
... (with c) signifies a reverse angle, extending to lowest deck, fitted to a channel bar. All dimensions in inches.		Size of Web Frame in inches.				Thickness of Stringer Plates in inches.	Intermediate Frames (inches).					
							Frame angle.	Reverse angle.	Alternative angle bulb	Alternative channel.	Double on webs. / Single on stringers.	Single on webs.
=21	=27	d=15	=19	=23	=27							
—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—
9 × 3 × ·50 B	11½×3½ ×·52C 11½×3½ ×·62B	15×·36	18×·38	21×·42	—	·32	4½×3 ×·32	3 ×3 ×·32	5½×3 ×·38	—	3½×3 ×·36	5 ×3½ ·54
9½ × 3½ × ·48C 10 × 3½ × ·56B	10½×3½ ×·48C 3½×3½ ×·48R	19×·40	22×·42	25×·46	30×·52	·36	6 ×3½×·36	3½×3 ×·36	7 ×3½×·42	—	3½×3½×·46	7 ×3½×·62
11 × 3½ × ·50C 3½ × 3½ × ·50R	—	28×·48	30×·52	34×·54	39×·60	·44	7 ×3½×·44	4 ×3½×·44	9 ×3½×·50	8 ×3½×·44	4 ×4 ×·58	—
—	—	37×·58	39×·62	42×·62	—	·52	—		—	10×4 ×·56	4½×4½×·70	—

Topside and Deck Plating at Upper, Awning, and Shelter

Longitudinal Number L × (B + D).	Breadth of Sheer Strake and Strake below.	Length ÷ Depth up to 10. Sheer strake.	Strake below.	Stringer Angle.	Stringer Plate.	Deck Plating.	Length ÷ Depth over Sheer strake.	Strake below.	Stringer Angle.
2,500	32	·28	·28	3 × 3 × ·28	18 × ·26	6 × $\overset{\text{T}}{\cdot 26}$	·32	·28	3 × 3 × ·28
7,000	38	·40	·40	3 × 3 × ·40	34 × ·38	9 × $\overset{\text{T}}{\cdot 38}$	·46	·40	3 × 3 × ·40
11,500	41	·48	·46	4 × 4 × ·46	48 × ·44	13 × $\overset{\text{T}}{\cdot 44}$	·54	·46	4 × 4 × ·46
18,000	43	·54	·52	4½ × 4½ × ·50	42 × ·48	·30	·62	·52	4½ × 4½ × ·50
36,000	48	·66	·64	5 × 5 × ·62	55 × ·52	·40	·78	·70	5 × 5 × ·62
56,000	52	·80	·76	5 × 5 × ·72	49 $\overset{\text{D}}{\times}$ ·60	·48	·98	·88	6 × 6 × ·72
80,000	58	1·00	·90	7 × 7 × ·83	57 $\overset{\text{D}}{\times}$ ·78	·68	$\overset{\text{D}}{\cdot 90}$	$\overset{\text{D}}{\cdot 90}$	8 × 8 × ·83

D = Double.

Cellular Double Bottoms.

Longitudinal Number L × (B + D).	Depth of Central Girder.	Thickness. Floor plates and Brackets.	Central girder.	Side girders.	Margin Plate.	Inner Bottom. Breadth, Middle Line Strake.	Thickness. Middle Line Strake.	In Holds generally.	In Engine-room.	In Boiler-room including Middle Line.
Up to 7,500	30	·28	·36	·28	·30	30	·34	·28	·32	·44
About 19,000	37	·34	·46	·34	·40	37	·44	·36	·42	·52
36,000	44	·40	·52	·40	·48	44	·52	·40	·50	·56
56,000	51	·48	·66	·48	·58	51	·60	·48	·58	·64
80,000	57	·54	·82	·54	·72	54	·70	·56	·66	·70

DECKS AND "LONG" BRIDGES. (All dimensions in inches.)

11 and up to 12.		Length ÷ Depth over 13 and up to 14.					Upper Dec Under 'Lon Bridges.	
Stringer Plate.	Deck Plating.	Sheer strake.	Strake below.	Stringer Angle.	Stringer Plate.	Deck Plating.	Stringer Plate.	Deck Plating.
22 × ·28	T 6 × ·28	·40	·28	3 × 3 × ·36	26 × ·32	T 6 × ·32	·24	T ·24
38 × ·40	T 9 × ·40	·56	·42	3½ × 3½ × ·48	42 × ·44	T 11 × ·44	·32	T ·32
52 × ·46	T 13 × ·46	·68	·52	4 × 4 × ·54	44 × ·50	·30	·40	·30
46 × ·52	·30	·80	·60	4½ × 4½ × ·60	50 × ·56	·38	·44	·30
59 × ·58	·42	1·06	·84	5 × 5 × ·70	63 × ·68	·46	·48	·38
D 51 × ·70	·52	D ·96	D ·90	7 × 7 × ·80	53 × ·82	·56	·52	·44
D 59 × ·92	·72	D 1·20	D 1·12	8 × 8 × ·92	61 × 1·04	·78	·62	·54

T = Tie-plates.

(All dimensions in inches.)

Angle Bars.				
(1) Top. (2) Bottom of Central Girder.	Connecting Margin Plate to Outer Bottom.	Frames and Reverses on Floors, Side Girder Angles, and Vertical Angles on Central and Margin Plate.	Vertical connecting Floors and Side Girders.	Intermediate Frames and Reverses where Floors are on alternate Frames.
3 × 3 × ·31 3½ × 3½ × ·36	3 × 3 × ·30	3 × 3 × ·28	2½ × 2½ × ·23	3½ × 3 × ·30 3 × 2½ × ·26
3½ × 3½ × ·44 4 × 4 × ·54	3½ × 3½ × ·40	3½ × 3½ × ·34	3 × 3 × ·34	5 × 3½ × ·38 3½ × 3 × ·34
3½ × 3½ × ·52 4½ × 4½ × ·60	4 × 4 × ·48	3½ × 3½ × ·42	3 × 3 × ·40	—
3½ × 3½ × ·60 5 × 5 × ·66	4 × 4 × ·58	3½ × 3½ × ·54	3½ × 3½ × ·48	—
4 × 4 × ·72 5 × 5 × ·80	4 × 4 × ·72	4 × 4 × ·60	3½ × 3½ × ·54	—

MAIN AND LOWER 'TWEEN DECK WATERTIGHT BULKHEADS. (All dimensions of plates and bars in inches.)

Depth from Upper Deck to lowest part of Bulkhead. Feet.	Thickness of Plating. At Floor or Inner Bottom.	Thickness of Plating. At Upper Deck.	Angles connecting Bulkhead to Inner or Outer Bottom Plating, or to Decks. Double Angles to Bottoms and Single Angles to Decks.	Angles connecting Bulkhead to Inner or Outer Bottom Plating, or to Decks. Single Angles to Outside Plating and Double Bottom.	Up to 8'.	13'	18'	21'	26'
Up to 8	·26	·26	—	3½ × 3½ × ·40	A 3 × 2½ × ·30	—	—	—	—
About 16	·30	·26	3 × 3 × ·30	4 × 4 × ·42	A 4 × 3 × ·36	A 5 × 3 × ·38	—	—	—
23	·34	·30	3½ × 3½ × ·34	5 × 5 × ·46	A 5 × 3 × ·40	6½ × 3 × ·40	8½ × 3 × ·46	8½ × 3 × ·46	—
31	·38	·30	4 × 4 × ·38	5 × 5 × ·54	5½ × 3 × ·40	8 × 3 × ·44	9½ × 3½ × ·52	10½ × 3½ × ·56	12 × 3½ × ·64
38	·42	·30	4½ × 4½ × ·44	6 × 6 × ·60	6 × 3 × ·40	9 × 3 × ·46	10½ × 3½ × ·60	12 × 3½ × ·60	Channel 12 × 4 × 4 × ·70 (D, up to 35')
49	·46	·30	4½ × 4½ × ·50	6 × 6 × ·64	7½ × 3 × ·42	10 × 3½ × ·52	12 × 3½ × ·60	—	—

A = Angle Bar.

collision bulkhead to be 24"; and on the opposite side horizontal stiffeners of angle bulb 1" deeper than frames in peak to be worked, 4' apart.

The thickness at bottom to be main-

·30, and ·34.

DECK BEAMS. (All dimensions, except length, in inches.)

Length of Beam amidships in feet.	Beams fitted to every Frame with Steel Deck.						Beams fitted to alternative Frames without Steel Deck.					
	Upper Deck Beams where one tier only is fitted.		Beams at Upper Deck (with more than one tier), Awning Deck, Shelter Decks, Forecastles, Poops, and Long Bridges.		Beams at other Decks. *Note.*—If for passengers only, the sizes in columns on the left may be taken in lieu.		Upper Deck Beams where one tier only is fitted.		Beams at Upper Deck (with more than one tier), Awning Deck, Shelter Decks, Forecastles, Poops, and Long Bridges.		Beams at other Decks. *Note.*—If for passengers only, the sizes in columns on the left may be taken in lieu.	
			A = Angle bar; the remainder are angle bulb.				A = Angle bar; the remainder are bulb plate.					
	Rows of Pillars = 1	= 3	= 1	= 3	= 1	= 3	= 1	= 3	= 1	= 3	= 1	= 3
17	A $3\frac{1}{2} \times 2\frac{1}{2} \times \cdot 30$	A $3 \times 2\frac{1}{2} \times \cdot 30$	—	—	—	—	A $4\frac{1}{2} \times 3 \times \cdot 34$	A $4 \times 3 \times \cdot 30$	—	—	—	—
29	A $5\frac{1}{2} \times 3 \times \cdot 34$	A $5 \times 3 \times \cdot 30$	A $5 \times 3 \times \cdot 34$	A $4 \times 2\frac{1}{2} \times \cdot 30$	$5\frac{1}{2} \times 3 \times \cdot 40$	$4 \times 3 \times \cdot 30$	$7 \times \cdot 34$	$6 \times \cdot 26$	$6 \times \cdot 34$	A $5\frac{1}{2} \times 3 \times \cdot 40$	$7 \times \cdot 40$	$6 \times \cdot 26$
41	$8 \times 3 \times \cdot 46$	$6 \times 3 \times \cdot 40$	$7 \times 3 \times \cdot 40$	A $5\frac{1}{2} \times 3 \times \cdot 34$	$7\frac{1}{2} \times 3 \times \cdot 42$	$5\frac{1}{2} \times 3 \times \cdot 34$	$10 \times \cdot 50$	$8 \times \cdot 40$	$9 \times \cdot 44$	$7 \times \cdot 30$	$10 \times \cdot 54$	$8 \times \cdot 40$
53	—	—	—	$7 \times 3 \times \cdot 40$	—	$7\frac{1}{2} \times 3 \times \cdot 42$	—	—	—	$9 \times \cdot 44$	—	$10 \times \cdot 50$
65	—	—	—	$8\frac{1}{2} \times 3\frac{1}{2} \times \cdot 48$	—	$9 \times 3\frac{1}{2} \times \cdot 50$	—	—	—	$11 \times \cdot 54$	—	$12 \times \cdot 60$
79	—	—	—	$10\frac{1}{2} \times 3\frac{1}{2} \times \cdot 58$	—	$11 \times 3\frac{1}{2} \times \cdot 62$	*Note.*—With 2 rows of pillars take sizes intermediate between 1 row and 3 rows.					

Widely Spaced Pillars.

umber. $\frac{\times B \times H}{100}$ ee description, p. 509.	Length of Pillar in feet. 6 to 8. If tubular, outside diameter × thickness.	6 to 8. If built of 4 angle bars, riveted together back to back.	12 to 14. If tubular.	12 to 14. If built of 4 angle bars.	18 to 20. If tubular.
12	6 × ·40	—	7 × ·40	4 × 4 × ·40	8 × ·40
24	8 × ·40	—	$8\frac{1}{2}$ × ·44	$4\frac{1}{2}$ × $4\frac{1}{2}$ × ·44	10 × ·40
45	11 × ·50	5 × 5 × ·50	12 × ·50	5 × 5 × ·60	12 × ·54
75	14 × ·60	6 × 6 × ·60	15 × ·60	6 × 6 × ·70	16 × ·60
115	18 × ·64	7 × 7 × ·70	18 × ·70	8 × 8 × ·70	18 × ·74

Girders at Heads of Widely Spaced Pillars.

umber. $\frac{\times B \times H}{100}$ ee description, p. 509.	Thickness of Intercostal Plate and Angle.	Sizes of Double Channel Bars riveted to Girder Plate below Beam. Where R is marked, a Rider Plate about ·15 thicker than Girder Plate is added. Depth of Beam in inches. 5	7	9	12
200	·34	7 × 3 × 3 × ·38	—	—	—
350	·40	8 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·46	7 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·40	7 × 3 × 3 × ·38	—
580	·44	11 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·60	9 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·60	8 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·46	7 × 3 × 3 × ·38
1000	·50	—	R 12 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·70	12 × 4 × 4 × ·64	10 × $3\frac{1}{2}$ × $3\frac{1}{2}$ × ·60
1800	·54	—	—	—	R 12 × 4 × 4 × ·72

(All dimensions, except in length, in inches.)

Length of Pillar in feet.				
18 to 20.	24 to 26.		28 to 30.	
If built of 4 angle bars.	If tubular.	If built of 4 angle bars.	If tubular.	If built of 4 angle bars.
$4\frac{1}{2} \times 4\frac{1}{2} \times \cdot 40$	$9 \times \cdot 44$	$5 \times 5 \times \cdot 50$	$10 \times \cdot 50$	$6 \times 6 \times \cdot 50$
$5 \times 5 \times \cdot 50$	$10 \times \cdot 50$	$5 \times 5 \times \cdot 60$	$11 \times \cdot 50$	$6 \times 6 \times \cdot 60$
$6 \times 6 \times \cdot 60$	$13 \times \cdot 54$	$6 \times 6 \times \cdot 64$	$13 \times \cdot 60$	$7 \times 7 \times \cdot 60$
$7 \times 7 \times \cdot 70$	$17 \times \cdot 60$	$7 \times 7 \times \cdot 74$	$18 \times \cdot 60$	$8 \times 8 \times \cdot 74$
$8 \times 8 \times \cdot 84$	—	—	—	—

Depth of Margin Plate in Double Bottom.					Thickness of Deck Planking.				
Transverse Number B+D.	Depth d from top of Margin Plate to lowest tier of Beams at side, in feet.				Longitudinal Number L × (B+D)	At Upper Decks.		At Awning or Shelter Decks, and on Erections.	
	7–10	13–16	19–22	25–27		Pine.	Teak.	Pine.	Teak
Up to 45	19	21	—	—	Up to 2,400	$2\frac{1}{2}$	—	2	—
About 58	24	25	27	—	3,700 5,200	$2\frac{3}{4}$ 3	$2\frac{1}{4}$ $2\frac{1}{2}$	$2\frac{1}{4}$ $2\frac{1}{4}$	— —
74	28	30	32	34	7,000	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{2}$	2
92	34	36	38	40	8,800 11,800	$3\frac{1}{2}$ $3\frac{3}{4}$	3 3	$2\frac{3}{4}$ $2\frac{3}{4}$	$2\frac{1}{4}$ $2\frac{1}{4}$
110	40	42	44	—	32,000	4	$3\frac{1}{4}$	3	$2\frac{1}{2}$

LLOYD'S RULES FOR YACHTS OF THE INTERNATIONAL RATING CLASSES.

These regulations are the outcome of the recommendation of the International Conference on Yacht Measurement, 1906, which decided that there should be scantling restrictions for racing yachts in all the countries represented (the principal European states). They have been prepared by the British and German Lloyd's and the Bureau Veritas in consultation; their aim is to arrange for such scantlings as will enable a yacht to withstand the strains consequent on racing, and afterwards to be converted into a serviceable cruiser. They apply to wood, composite, and steel yachts rated as follows:—

Rating in metres	5	6	7	8	9	10	12	15	19	23
Corresponding No. of feet .	16·4	19·7	23·0	26·2	29·5	32·8	39·4	49·2	62·3	75·4

The rating in metres or feet is $\frac{1}{2}(\text{L} + \text{B} + \frac{1}{2}\text{G} + 3d + \frac{1}{3}\sqrt{\text{S}} - \text{F})$; where L = length on water-line + (*a*) the difference between the girth, covering board to covering board, at the bow water-line ending, and twice the free-board at that point, + (*b*) one-fifth of the difference between the girth, covering-board to covering-board, at the stern water-line ending, and twice the free-board at that point.

B = the greatest beam, including wales, doubling planks, and mouldings.

G = the greatest chain girth between upper sides of covering-boards round the keel, less twice the free-board at the same station; alternatively if the underside of keel be straight, the above may be measured anywhere abaft ·55 L.W.L. length from the bow, provided that the maximum chain girth does not exceed it by more than 3 per cent. If there be a hollow in the fore and aft under water, G and *d* shall be taken under an imaginary line excluding such hollow.

d = the difference between the chain girth G and the skin girth between the same points measured along the outline of the cross-section.

S = the sail area as measured under Y.R.A. rules.

F = twice the free-board at girth station + free-board at bow water-line ending + free-board at stern water-line ending, the whole divided by four.

All measurements to be taken without the crew on board.

A selection of the scantlings for wood and steel yachts is given in the following tables; those for intermediate ratings can be obtained approximately by interpolation.

No rules were formulated regarding the masting and rigging.

Steel Yachts.

The size of the stem may be reduced uniformly from full size at heel to three-quarters area at head. The stern-post similarly from the counter to the head. The scarves to keel to have a length nine times the bar keel thickness.

Reverse frames to be fitted to all floors; in 12 and 15 metre yachts to extend alternately to bilge stringer; in 19 and 23 metre yachts to extend alternately to cabin sole beams and 4 feet above.

Beams to be pillared at the middle in way of masts, windlasses, deckhouses, and large openings, and about four frames apart for yachts 15 metres and above. Half-beams to be attached by double lugs to carlings or coamings. The depths of the knees to be 6″ for $1\frac{3}{4}$″ beam, 9″ for $3\frac{1}{4}$″ beam, $12\frac{1}{2}$″ for 5″ beam, and so intermediately; to be connected by four rivets to frame; depth at throat to be 60 per cent that of knee.

Pine decks to have the grain vertical. For 8 metre yachts and less, the planking thickness may be reduced by $\frac{1}{16}$″ when covered with canvas and painted.

Butts of outside plating to be planed; they are to be shifted as by Lloyd's rules for ships. Those of keel plate, sheer strake, and deck stringer to be generally double-riveted; the remainder, except in the largest classes, single-riveted. The riveting to be spaced four diameters in outside plating (at edges $4\frac{1}{2}$ diameters), and seven diameters in frames, beams, etc.; the spacing is somewhat closer with the larger sizes of rivets. See also p. 290. The sizes of the riveting to be in accordance with the following table :—

Thickness of plates or angles in inches—

·10 and under ·15	·15 and under ·20	·20 and under ·25	·25 and under ·30	·30 and under ·35	·35 and under ·50	·50 and under ·60

Diameter of rivets in inches—

$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$

The rivet hole to be $\frac{1}{16}$″ larger than the rivet; the diameter at the top of countersink (in outside plating) being greater than that of the hole by about half the rivet diameter.

Wood Yachts.

The table scantlings are, except for decks, those required for oak, East India teak, greenheart, acacia, English elm, American rock elm, and mahogany weighing at least 35 lb. per cubic foot. The scantlings are to be increased by 5 per cent with pitchpine, by 10 per cent for Oregon pine, larch, Kaurie pine, lighter mahogany, fir (various descriptions), and red pine, and by 20 per cent for spruce or yellow pine. It is recommended that any steel used be galvanized.

The keel may be scarphed for 12 metre and larger yachts, the length of scarph being 3′ 6″ to 5′ 5″ according to size. If

SCANTLINGS OF

Portion of Structure (all dimensions in inches).		
Keel, stem, and sternpost		
Rudder.	Diameter at head	
	Section at heel	
	Thickness of plates	
	Diameter of pintles	
Framing.	Frames	
	Reverses	
	Frame spacing	
	Floor plates.	Depth at centre
		Thickness
	Web frames.	Number on each side
		Size of plate
Beams.	At alternate frames.	Through beams for $\frac{3}{4}$ L
		Do. at ends. All half beams
	At every frame.	Through beams for $\frac{3}{4}$ L
		Do. at ends. All half beams
Hollow pillars (iron or steel). Outside diameter and thickness		
Outside plating	Keel plate	
	Plating generally	
	Upper deck sheerstrake	
Upper deck Stringer plates	For three-quarter L amidships	
	At ends	
Tie plates on upper deck beams	Number of pairs of diagonal tie plates	
	Breadth and thickness	
Upper deck and bilge stringer angles		
Upper deck planking.	Thickness of planking.	Beams at every frame
		Beams at alternate frames
	Diameter of screw fastenings	

Steel Yachts.

International Rating Class in metres.

5	7	10	15	23
2¾ × $\frac{5}{16}$	3¼ × $\frac{7}{16}$	4 × ⅝	4½ × $\frac{13}{16}$	5½ × 1$\frac{1}{16}$
1⅛ ⅞ × ¾ ·08 —	1¼ 1 × ¾ ·10 —	1½ 1¼ × 1⅛ ·14 —	2 1¾ × 1½ ·16 1½	3 2½ × 2 ·24 2
1¼ × 1 × ·12 1 × 1 × ·12 12	1¼ × 1¾ × ·14 1¼ × 1 × ·12 14	1¾ × 1¾ × ·16 1½ × 1½ × ·14 17	2 × 2 × ·20 2 × 1¾ × ·16 19	2½ × 2½ × ·25 to ·22 2¼ × 2¼ × ·22 21
6 ·10	8 ·12	11 ·14	13 ·18 to ·16	16 ·25 to ·20
— —	— —	— —	— —	2 14 × ·25
2 × 1½ × ·12 2 × 1¼ × ·12	2¼ × 1¾ × ·14 2 × 1½ × ·14	3 × 2 × ·18 2¼ × 1¾ × ·18	3½ × 2½ × ·25 3½ × 2¼ × ·20	5 × 3 × ·30 4¼ × 3 × ·25
2 × 1¼ × ·12 1¾ × 1¼ × ·12	2 × 1½ × ·14 2 × 1½ × ·12	2¼ × 1½ × ·18 2¼ × 1½ × ·16	3 × 2 × ·20 3 × 1¾ × ·18	4 × 2¼ × ·25 3½ × 2 × ·22
—	—	—	1⅞ × ·18	2⅜ × ·18
24 × ·14 ·10 17 × ·10	26 × ·18 ·12 19 × ·14 to ·12	29 × ·26 ·14 and ·16 alternately 22 × ·20 to ·16	32 × ·35 ·18 and ·20 alternately 24 × ·26 to ·20	36 × ·50 to ·45 ·24 28 × ·36 to ·24
6½ × ·10 4 × ·10	8 × ·12 5½ × ·12	10 × ·16 7 × ·14	14 × ·22 10 × ·18	19½ × ·26 15 × ·22
1 2 × ·10	1 2½ × ·12	2 3¼ × ·16 to ·14	2 4 × ·22 to ·18	2 6 × ·26 to ·22
1¼ × 1¼ × ·10	1½ × 1½ × ·12	2 × 2 × ·16 to ·14	2¼ × 2¼ × ·22 to ·18	2½ × 2½ × ·26 to ·22
·74 ·90	·96 1·12	1·34 1·50	1·69 1·85	2·24 2·40
·21	·25	·33	·36	·39

SCANTLINGS OF

Portion of Structure (all dimensions in inches).		
Keel	Moulding	
	Sectional area in square inches	
Siding and moulding of stem and sternpost, siding of after deadwood, diameter rudder head		
Bent wood frames only.	Siding × Moulding	
	Spacing, centre to centre	
'Grown' frame timbers only.	Siding	
	Moulding.	At heel
		At head
	Spacing, centre to centre	
Floors.	Wood floors on grown timbers – moulding × siding	
	Angle steel floors on 'grown' frame timbers.	Length of arms
		Angle steel
	Angle steel floors on bent wood frames.	Length of arms
		Angle steel
Web frames.	Number each side	
	Size of plate	
	Size of face angle	
Sectional area of upper deck shelf in square inches		
Sectional area of bilge stringer in square inches		
Thickness of outside planking		
Beams.	Spacing, centre to centre	
	Through beam for ⅗ L amidships.	At middle of beam
		At end of beam
	Wrought-iron hanging knees to deck beams.	Number each side
		Length of arms
		At throat
		At point
Thickness of upper deck planking		
Diameter of fastenings.	In keel, dead wood, stem, sternpost, floors to grown frames	
	Grown frames to iron floors and to deadwood	
	Bent frames to floors and deadwood, deck shelves, etc.	
	Outside planking to grown frames, (1) bolts, (2) screws	
	Outside planking to bent frames, (1) bolts, (2) screws	

WOOD YACHTS.

International Rating Class in metres.				
5	7	10	15	23
3 18	4 32	$5\frac{1}{2}$ 61	$7\frac{1}{2}$ 113	10 200
3	$3\frac{1}{2}$	$4\frac{1}{4}$	6	9
$\frac{7}{8} \times \frac{3}{4}$ $5\frac{1}{2}$	$1\frac{3}{8} \times 1\frac{1}{8}$ $6\frac{1}{2}$	$2\frac{1}{8} \times 1\frac{7}{8}$ 8	— —	— —
1	$1\frac{1}{2}$	$2\frac{5}{8}$	4	$6\frac{1}{2}$
$1\frac{1}{8}$ $\frac{7}{8}$	$1\frac{7}{8}$ $1\frac{5}{8}$	3 $2\frac{1}{4}$	$4\frac{1}{2}$ $3\frac{1}{2}$	7 $5\frac{1}{2}$
9	11	14	16	18
$2\frac{1}{2} \times 1$	$3\frac{1}{2} \times 1\frac{1}{2}$	$5 \times 2\frac{3}{8}$	$7\frac{1}{2} \times 4$	$11\frac{1}{2} \times 6\frac{1}{2}$
16 $1\frac{1}{2} \times 1 \times {}^{\cdot}15$	20 $2 \times 1\frac{1}{2} \times {}^{\cdot}18$	26 $2\frac{1}{2} \times 2\frac{1}{4} \times {}^{\cdot}24$	34 $3\frac{1}{2} \times 2\frac{1}{2} \times {}^{\cdot}28$	48 $5 \times 3 \times {}^{\cdot}35$
12 $\frac{7}{8} \times \frac{7}{8} \times {}^{\cdot}14$	14 $1\frac{1}{8} \times 1\frac{1}{8} \times {}^{\cdot}14$	19 $1\frac{1}{2} \times 1\frac{1}{2} \times {}^{\cdot}15$	26 $2 \times 2 \times {}^{\cdot}20$	— —
— — —	— — —	— — —	4 $7 \times {}^{\cdot}18$ $2 \times 1\frac{3}{4} \times {}^{\cdot}16$	6 $14 \times {}^{\cdot}25$ $2\frac{1}{4} \times 2\frac{1}{4} \times {}^{\cdot}22$
$3\frac{1}{2}$ — ·50	6 — ·75	13 10 1·14	24 18 1·65	46 — 2·25
7	9	13	19	27
$1\frac{1}{2} \times 1$ 1×1	$2 \times 1\frac{1}{4}$ $1\frac{1}{4} \times 1\frac{1}{4}$	$2\frac{3}{4} \times 1\frac{3}{4}$ $1\frac{3}{4} \times 1\frac{3}{4}$	$3\frac{3}{4} \times 2\frac{3}{4}$ $2\frac{3}{4} \times 2\frac{3}{4}$	$5\frac{1}{2} \times 4\frac{1}{2}$ $4\frac{1}{2} \times 4\frac{1}{2}$
3 12 $\frac{3}{4} \times \frac{5}{16}$ $\frac{3}{4} \times \frac{1}{8}$	4 14 $1 \times \frac{3}{8}$ $\frac{7}{8} \times \frac{3}{16}$	7 19 $1\frac{3}{8} \times \frac{3}{4}$ $1\frac{1}{4} \times \frac{1}{4}$	10 26 $2\frac{1}{8} \times 1$ $1\frac{3}{4} \times \frac{3}{8}$	14 36 $3 \times 1\frac{1}{4}$ $2\frac{1}{4} \times \frac{5}{8}$
·50	·75	1·14	1·65	2·25
$\frac{6}{16}$ $\frac{4}{16}$ $\frac{3}{16}$ $\frac{5}{32}$ ·19	$\frac{7}{16}$ $\frac{6}{16}$ $\frac{3}{16}$ $\frac{3}{16}$ ·26	$\frac{10}{16}$ $\frac{7}{16}$ $\frac{5}{16}$ $\frac{5}{16}$ ·39	$\frac{12}{16}$ $\frac{9}{16}$ $\frac{7}{16}$ $\frac{6}{16}$ ·47	$\frac{14}{16}$ $\frac{11}{16}$ $\frac{10}{16}$ $\frac{8}{16}$
·10 ·15	·14 ·18	·20 ·25	·24 ·30	—

a keelson be fitted its sectional area may be included in that of the keel.

The heels of frames to be let into the keel. The web frames required in large yachts are to be fitted in way of mast, rigging, and lead keel; also for'd and aft in the largest yachts. Efficient breasthooks and crutches to be fitted at the ends of yachts.

Beams to be dovetailed or dowelled to the shelf; and as far as possible to be fitted to the frames.

Butts of outside planking to be 5 feet apart in adjacent and 4 feet in adjoining strakes. There should be three strakes between butts on the same timber. For deck planking see under "Steel Yachts".

Through bolt fastenings to be clenched on rings of the same metal as the bolts except in 5 metre yachts. All iron fastenings to be galvanized. The number of fastenings attaching outside planking to frames are: for planking 1" to 1½", one or two up to 5" width of planks, two from 5" to 7", three from 7" to 10". There should be at least as many fastenings (and at least two) at the butts.

All bolts for attaching lead keels to be of copper or yellow metal. Their diameter is given by a table where it depends on the ratio of depth to breadth at upper edge of keel, and on the product of its sectional area in square inches by the fore and aft spacing of the bolts in feet. With ratio 1·5 to 2·0 the diameter is $\frac{9}{16}$" for product under ·5, 1" for 1·7 to 2·8, 1¾" for 6·8 to 8·0, 2¼" for 12·0 to 13·6, and so intermediately. In all but the smallest sizes (minimum $\frac{9}{16}$") deduct ⅛" for each reduction of ·5 in the ratio. It is recommended that the bolts be fitted alternately on opposite sides of the middle line.

Equipment of Yachts.

To be in accordance with the table. Anchor stocks to be one-quarter the weight of the anchor. Two end shackles should be included in the weight of each cable.

Minimum Requirements of Anchors, Chains, and Hawsers for Yachts of the International Racing Classes.

Rating Class in Metres.	Anchors.				Chain Cables.				Hemp or Manilla Hawsers.		
	Number.	Weight in lb., *ex* Stock.			Length (fathoms).	Diameter (inches).	Minimum weight (lb.)		Length (fathoms).	Circumference.	
		1st.	2nd.	3rd.			Stud Link.	Short Link.		in.	in.
5	1	25	—	—	—	—	—	—	15	2	—
7	1	35	—	—	—	—	—	—	20	2¼	—
10	2	68	51	—	40	$\frac{6}{16}$	373	398	35	2¾	2
15	2	154	116	—	60	$\frac{8}{16}$	970	1083	45	3½	2½
23	3	392	294	168	115	$\frac{12}{16}$	3709	4031	75	6	3½

Board of Trade Tests for Anchors (Extract).

Weight of Anchor, *ex* Stock.	Proof Strain.			Weight of Anchor, *ex* Stock.	Proof Strain.			Weight of Anchor, *ex* Stock.	Proof Strain.		
cwt.	tons.	cwt.	qrs.	cwt.	tons.	cwt.	qrs.	cwt.	tons.	cwt.	qrs.
200	96	15	0	52	43	12	2	26	25	12	2
190	94	5	0	51	43	0	0	25	24	15	0
180	91	15	0	50	42	7	2	24	23	17	2
170	89	5	0	49	41	15	0	23	23	2	2
160	86	15	0	48	41	2	2	22	22	7	2
150	84	2	2	47	40	10	0	21	21	12	2
140	81	0	0	46	39	17	2	20	20	15	0
130	77	17	2	45	39	5	0	19	19	17	2
120	74	15	0	44	38	12	2	18	19	0	0
110	71	0	0	43	37	17	2	17	18	5	0
100	67	5	0	42	37	2	2	16	17	7	2
90	63	5	0	41	36	10	0	15	16	10	0
80	58	10	0	40	35	15	0	14	15	12	2
75	56	5	0	39	35	2	2	13	14	15	0
70	53	15	0	38	34	10	0	12	13	17	2
67½	52	7	2	37	33	15	0	11	12	17	2
65	51	0	0	36	33	2	2	10	12	0	0
62½	49	15	0	35	32	7	2	9	11	2	2
60	48	7	2	34	31	12	2	8	10	2	2
59	47	15	0	33	30	17	2	7	9	5	0
58	47	5	0	32	30	2	2	6	8	5	0
57	46	12	2	31	29	7	2	5	7	7	2
56	46	0	0	30	28	12	2	4	6	7	2
55	45	7	2	29	27	17	2	3	5	10	0
54	44	15	0	28	27	2	2	2	4	10	0
53	44	5	0	27	26	7	2				

Note.—The strain is tensile, and is to be applied on the arm or palm, at a spot which, measured from the extremity of the bill, is one-third of the distance between it and the centre of the crown. There must be no more than $\frac{3}{4}$ in. permanent set measured between fluke and shackle pin.

ADMIRALTY TESTS AND WEIGHTS OF STUD-LINKED CHAIN CABLE.

Diameter of cable.	Number of common links in each length of cable.	Weight of 100 fathoms of cable, with the necessary joining shackles, etc.			Approximate weight of				Proof load to be borne without injury.
					One joining shackle.	One end link.	One intermediate link.	One common link.	
in.		cwt.	qr.	lb.	lb.	lb.	lb.	lb.	tons.
4	51	768	0	0	535·7	272	256	204·8	201·6
$3\frac{3}{4}$	55	675	0	0	441	224	210·5	164·75	189·8
$3\frac{1}{2}$	59	588	0	0	359	182·25	171·5	134	176·4
$3\frac{1}{4}$	63	507	0	0	287·5	145·9	137	107·25	161·6
3	69	432	0	0	226·1	114·75	108	84·38	145·8
$2\frac{7}{8}$	73	396	3	0	199	101·1	95	74·3	137·6
$2\frac{3}{4}$	75	363	0	0	174	88·38	83	65	129·3
$2\frac{11}{16}$	77	346	2	21	162·4	82·5	77·4	60·7	125·1
$2\frac{9}{16}$	83	315	0	21	140	71·5	66·3	52·6	116·7
$2\frac{1}{2}$	85	300	0	0	130	66·4	62·5	48·8	$112\frac{1}{2}$
$2\frac{3}{8}$	89	270	3	0	112	56·9	53·5	41·9	$101\frac{1}{2}$
$2\frac{1}{4}$	95	243	0	0	95	48·4	45·5	35·6	$91\frac{1}{8}$
$2\frac{1}{8}$	99	216	3	0	80	40·75	38·3	30	$81\frac{1}{4}$
2	107	192	0	0	67	34	32	25	72
$1\frac{7}{8}$	115	168	3	0	55·25	28	26·33	20·6	$63\frac{1}{4}$
$1\frac{3}{4}$	123	147	0	0	44·9	22·78	21·5	16·75	$55\frac{1}{8}$
$1\frac{5}{8}$	133	126	3	0	36	18·25	17·2	13·4	$47\frac{1}{2}$
$1\frac{1}{2}$	145	108	0	0	28	14·34	13·5	10·5	$40\frac{1}{2}$
$1\frac{3}{8}$	157	90	3	0	21·75	11	10·37	8·2	34
$1\frac{1}{4}$	175	75	0	0	16·31	8·32	7·75	6·1	$28\frac{1}{8}$
$1\frac{1}{8}$	195	63	3	4	11·87	6·10	5·7	4·5	$22\frac{3}{4}$
1	221	52	3	6	8·37	4·25	4	3·2	18
$\frac{15}{16}$	237	46	1	18	6·89	3·5	3·29	2·68	$15\frac{4}{5}$
$\frac{7}{8}$	253	40	1	20	5·61	2·84	2·66	2·2	$13\frac{3}{4}$
$\frac{3}{4}$	295	29	2	2	3·53	1·79	1·68	1·4	$10\frac{1}{8}$
$\frac{11}{16}$	321	24	3	23	2·72	1·37	1·29	1·1	$8\frac{1}{2}$
$\frac{5}{8}$	355	20	2	14	2·04	1·03	1·03	·8	7
$\frac{9}{16}$	395	16	2	23	1·49	·75	·702	·58	$5\frac{1}{2}$
$\frac{1}{2}$	445	13	0	22	1·04	·53	·47	·41	$4\frac{1}{2}$
$\frac{7}{16}$	509	10	0	12	·7	·34	·33	·28	$3\frac{1}{2}$
$\frac{3}{8}$	595	7	1	20	·44	·22	·21	·18	$2\frac{17}{32}$

The breaking loads of the several sizes of cables are 50 per cent above the proof load; and these latter are equivalent to the following stresses per circular $\frac{1}{8}$ inch of iron, viz.: 4 inch, 441 lb.; $3\frac{1}{2}$ inch, 504 lb.; $3\frac{1}{4}$ inch, 535·5 lb.; 3 inch, 567 lb.; $2\frac{7}{8}$ inch, 582·7 lb.; $2\frac{3}{4}$ inch, 598·5 lb.; $2\frac{9}{16}$ inch, 606·4 lb.; $2\frac{9}{16}$ inch, 622 lb.; $2\frac{1}{2}$ inch and under, 630 lb. The proof load for any cable under $2\frac{9}{16}$ inch is (diameter)$^2 \times 18$.

Note.—The Board of Trade proof tests are the same as above; the breaking tests are also alike for $1\frac{3}{8}$ inches and smaller sizes; above they are slightly smaller. viz.: $1\frac{1}{2}''$, 58·7; 2″, 100·8; $2\frac{1}{2}''$, 157·5; 3″, 204·1; $3\frac{1}{2}''$, 246·9; 4″, 282·2; being 40 per cent above proof for all sizes larger than $1\frac{1}{2}$ inches.

The breaking tests to be applied to 3 links in each $12\frac{1}{2}$ fathoms (Admiralty), or ch 15 fathoms (Board of Trade).

Admiralty Tests and Weights of Rigging Chain and Cat Chain.

Diameter of Chain.	Breaking Strain.	Proof Strain.	Weight per Fathom.	Diameter of Chain.	Breaking Strain.	Proof Strain.	Weight per Fathom.	
							Rigging Chain.	Cat Chain.
in.	Tons.	Tons.	lb.	in.	Tons.	Tons.	lb.	lb.
1/8	·43	·19	2·0	11/16	12·65	5·625	30·0	—
3/16	·92	·41	3·0	3/4	15·19	6·75	36·0	35·75
1/4	1·69	·75	4·75	13/16	17·72	7·875	39·0	—
5/16	2·53	1·125	6·75	7/8	20·53	9·125	48·0	49·5
3/8	3·66	1·625	9·5	15/16	23·625	10·5	53·0	—
7/16	5·06	2·25	13·25	1	27·00	12·00	61·0	64·5
1/2	6·75	3·00	17·0	1 1/8	34·31	15·25	73·0	79·75
9/16	8·44	3·75	21·0	1 1/4	42·19	18·75	92·0	96·0
5/8	10·41	4·625	25·0	1 3/8	50·91	22·625	108·0	116·0

Note.—The above breaking strains are two and a quarter times the proof strain; a piece of seven links out of each fifty fathoms being tested. The working strain for cranes, etc., should not exceed two-ninths the breaking strain or one-half the proof strain.

For proportions of chains see p. 538.

The Board of Trade proof tests for short link chain cables are in accordance with the above table, but the breaking strains (applied to three links in each fifteen fathoms) are only double the proof tests.

Admiralty Tests and Weights of Pitched Chain.

Diameter of Iron.	Inside Length of Link.	Inside Width of Link.	Proof Load.	Weight per Fathom.		
Inch.	Inches.	Inches.	Tons.	lb.	oz.	
7/32	3/4	9/32	23/40	2	8	Chain for Pulley Blocks.
1/4	3/4	9/32	3/4	3	12	
9/32	29/32	3/8	1	4	11	
5/16	7/8	3/8	1 1/8	6	2	
11/32	63/64	13/32	1 8/20	6	11	
3/8	31/32	7/16	1 5/8	8	3	
7/16	1 5/32	1/2	2 1/4	10	14	
1/2	1 3/8	9/16	3	13	4	
9/16	1 19/32	5/8	3 3/4	16	15	
5/8	1 7/8	11/16	4 5/8	21	4	
5/8	1 9/16	25/32	4 5/8	26	8	Steering Chain.
3/4	1 7/8	15/16	6 3/4	36	8	
7/8	2 3/16	1 3/32	9 1/8	49	0	

Note.—The breaking strain is double the proof strain, and is applied to a piece of seven links out of each fifty fathoms.

LLOYD'S REQUIREMENTS FOR

Equipment Number.	Bower Anchors.*		Stream* Anchor.	Kedge* Anchor.	Stud-chain Cable.	
	Weight of heaviest.	Combined weight.	Weight.	Weight.	Length.	Size.
	cwt.	cwt.	cwt.	cwt.	fath.	inches.
1,600 to 2,100	3½	7	¾	½	120	$\frac{11}{16}$
3,400 to 3,900	6½	13	2	1	165	$\frac{15}{16}$
5,300 to 5,900	12	34½	4	2	195	$1\frac{3}{16}$
7,700 to 8,400	19	54	6½	3¼	240	$1\frac{7}{16}$
11,100 to 12,300	27¾	79	8¾	4½	270	$1\frac{11}{16}$
16,800 to 18,600	36½	104	11¼	5½	270	$1\frac{15}{16}$
27,900 to 30,800	48	137	17	8½	300	$2\frac{3}{8}$
2,400 to 3,000	3	7	¾	½	120	$\frac{11}{16}$
4,800 to 5,400	6½	13	2¾	1	165	$\frac{15}{16}$
7,400 to 8,100	11¾	33½	4¼	2	195	$1\frac{3}{16}$
10,600 to 11,600	18¾	53½	6	3	210	$1\frac{7}{16}$
15,200 to 16,700	26½	75	8½	4½	240	$1\frac{11}{16}$
22,700 to 25,000	36	103	12	5½	270	$1\frac{15}{16}$
32,200 to 34,800	48	136½	16¼	7	270	$2\frac{3}{16}$
43,200 to 46,000	61½	175½	22	10	300	$2\frac{7}{16}$
54,600 to 57,600	76	217	28	14	330	$2\frac{11}{16}$
67,000 to 70,200	91	259	34	18	330	$2\frac{15}{16}$
80,200 to 83,800	105½	301	40¾	22	330	$3\frac{3}{16}$
100,200 to 105,000	127	362	49½	27	330	$3\frac{1}{2}$

hree bower anchors are required, except for equipment numbers less tha
ailing ships) or 6,000 (steam ships) when two only are necessary. If stockle
per cent. to weight and increase test accordingly. All weights given are
this should weigh at least ¼ that of the weight in the table.

Stream, Chain, or Steel Wire.			Towline: Hemp or Steel Wire.			Hawsers and Warps.†	
Length.	Size (chain).	Size (steel wire).	Length.	Size (hemp).	Size (steel wire).	Size.	Size.
Fathoms	Inches.	Inches.	Fathoms	Inches.	Inches.	Inches.	Inches.
45	$\frac{7}{16}$	—	75	5	$1\frac{3}{4}$	3	—
45	$\frac{9}{16}$	2	75	$6\frac{1}{2}$	$2\frac{1}{4}$	4	—
60	$\frac{11}{16}$	$2\frac{3}{4}$	75	8	$2\frac{3}{4}$	$5\frac{1}{2}$	—
60	$\frac{13}{16}$	3	75	$9\frac{1}{2}$	$3\frac{1}{4}$	7	—
75	$\frac{15}{16}$	$3\frac{1}{2}$	90	$10\frac{1}{2}$	$3\frac{1}{4}$	9	$5\frac{1}{2}$
75	$1\frac{1}{16}$	4	90	11	$3\frac{1}{2}$	$10\frac{1}{2}$	$6\frac{1}{2}$
120	$1\frac{1}{4}$	$4\frac{3}{4}$	120	$4\frac{3}{4}$	47	13	9
45	$\frac{1}{2}$	—	75	$5\frac{1}{2}$	2	3	—
45	$\frac{5}{8}$	$2\frac{1}{4}$	75	7	$2\frac{1}{2}$	5	—
60	$\frac{13}{16}$	3	75	$8\frac{1}{2}$	$2\frac{3}{4}$	6	—
60	$\frac{15}{16}$	$3\frac{1}{2}$	90	$9\frac{1}{2}$	$3\frac{1}{4}$	6	5
75	$1\frac{1}{16}$	4	90	11	$3\frac{1}{2}$	2 of 6	2 of 5
90	$1\frac{1}{8}$	$4\frac{1}{4}$	100	12	4	2 of 7	2 of 6
90	$1\frac{1}{4}$	$4\frac{3}{4}$	120	14	$4\frac{3}{4}$	2 of 8	2 of 7
120	$1\frac{5}{16}$	5	130	15	$5\frac{3}{4}$	2 of 8	2 of 8
120	$1\frac{1}{2}$	6	130	17	7	2 of 8	2 of 8
150	$1\frac{11}{16}$	$6\frac{1}{2}$	140	—	$7\frac{1}{2}$	3 of 8	2 of 8
150	$1\frac{7}{8}$	7	140	—	$7\frac{1}{2}$	3 of 8	3 of 8
150	2	$7\frac{1}{2}$	150	—	8	3 of 8	3 of 8

† Each hawser or warp has a length of 90 fathoms, except in steamships whose equipment number lies between 40,400 and 57,600, when it is 100 fathoms, and above 57,600 it is 120 fathoms.

otes on Lloyd's Requirements for Anchors and Cables (*p.* 530).

For Board of Trade tests of anchors see p. 527; for cables e p. 528; for Lloyd's tests for steel wire rope see p. 577 ff.

Cast steel anchors shall stand being dropped twice through ! feet (15 feet for 15 cwt. and below) as follows:) horizontally on an iron slab, (*b*) crown downwards on vo iron blocks which receive it on the middle of each arm. hey shall afterwards be well hammered with a 7 lb. sledge-ımmer. A test piece, 1″ diameter and 8″ long, shall stand ·nding cold through 90° with an inner radius of 1¼″. Each ıchor shall be properly annealed.

SUPPLY OF ANCHORS AND CABLES TO WARSHIPS.

Class of Ship.	Displacement in tons.	Bower Anchors.		Stream and Kedge Anchors.		Stud-link Cable.		Flexible Steel Wire Rope.	
		No.	Cwt.	No.	Cwt.	Length in fathoms.	Size in inches.	Length in fathoms.	Size in inches.
Battleship . .	20,000	3	130	1 4	42 5	475	$2\frac{5}{8}$	—	—
Battle cruiser .	28,000	3	150	1 4	46 5	500	3	—	—
2nd class cruiser	6,000	3	80	1 1 1	24 10 8	350	$2\frac{1}{8}$	150	6
3rd class cruiser	3,000	3	54	1 1 1	14 8 3	350	$1\frac{7}{8}$	150	$5\frac{1}{2}$
Sloop	1,000	3	28	1 1 1	9 5 3	$312\frac{1}{2}$	$1\frac{3}{8}$	—	—
Gunboat . . .	700	3	14	2 1	6 4	225	$1\frac{1}{8}$	—	—
T.B. Destroyer .	1,100	1 1	20 18	1	3	150	$1\frac{1}{8}$	100	$3\frac{1}{2}$

The equipment number = length × (greatest moulded ›readth + depth from top of keel to top of upper deck beam ıt side amidships). In awning or shelter-deck vessels measure lepth to second deck or to 8 feet below top deck, whichever

is greater. For erections in steamships add product of height and length of erection multiplied by one for raised quarter deck, by $\frac{3}{4}$ for awning or shelter deck, poop, bridge, or forecastle, by $\frac{1}{2}$ for erections not extending to the side. For sailing ships with erections add $\frac{1}{16}$ to the number.

The second bower anchor may be $7\frac{1}{2}$ per cent lighter than the heaviest, and the third (if any) 15 per cent lighter; or (in steamships) the three anchors may be of equal weight provided that their collective weight complies with the table. The weight of anchor stocks must be one-quarter that of the anchor specified. The heads of stockless anchors must be three-fifths the total weight.

For short Channel crossings only two bower (the second 15 per cent lighter) and one stream anchor need be carried.

Stockless stream and kedge anchors must be 25 per cent greater in weight than that specified.

Cables may be of unstudded close-link chain, if their proof strain be two-thirds that required for studded chain.

Flexible steel wire rope of six strands with twenty-four wires in each strand, are admitted if the diameter of each wire be one-fifty-sixth circumference of rope; the breaking test must be equal to that of the rope required in the table; the circumference will be about $\frac{3}{4}''$ less for sizes $6\frac{1}{4}''$ and above, and $\frac{1}{2}''$ less for smaller sizes.

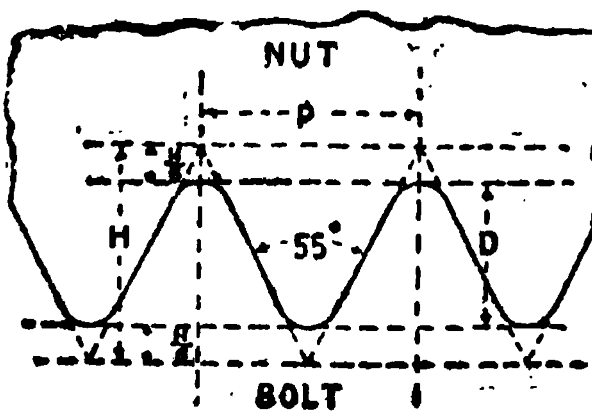
When any length of chain cable is worn so that the mean diameter at its worn part bears the following ratio to its original diameter it is to be renewed.

	Thirty-seconds of an Inch.								
Original diameter	22	24	34	44	54	62	72	82	92
Reduced ,,	20	21	30	39	48	55	64	73	82

BRITISH STANDARD PIPES AND SCREWS.

SECTION OF B.S. WHITWORTH THREAD (p. 534).

FIG. 241.



British Standard Pipe Flanges † (Selection).

For working Steam pressures of 55 lb. per square inch and Water pressure of 200 lb. per square inch.

Internal Diameter of Pipe.	Diameter of Flange.	Diameter of Bolt Circle.	Number of Bolts.	Diameter of Bolts.	Thickness of Flanges. Cast-iron and Steel or Iron Welded-on.	Thickness of Flanges. Cast Steel and Bronze.	Thickness of Flanges. Stamped or Forged Wrought-iron or Steel.
in.	in.	in.		in.	in.	in.	in.
½	3¾	2⅝	4	½	½	⅜	3/16
¾	4	2⅞	4	½	½	⅜	3/16
1	4½	3¼	4	½	½	⅜	3/16
1¼	5¼	3⅞	4	½	⅝	½	¼
2	6	4½	4	⅝	¾	9/16	5/16
3	7¼	5¾	4	⅝	¾	9/16	⅜
4	8½	7	4	⅝	⅞	11/16	⅜
5	10	8¼	8	⅝	⅞	11/16	½
6	11	9¼	8	⅝	⅞	11/16	½
9	14½	12¾	8	⅝	1	¾	⅝
12	18	16	12	¾	1⅛	⅞	⅝
18	25¼	23	12	⅞	1⅜	1⅛	⅞
24	32½	29¾	16	1	1⅝	1⅜	1⅛

Note.—Pipes of 1½, 2½, 3½, 7, 8, 10, 14, 15, 16, 20, and 21 inches internal diameter and tables for other working pressures are given in the Committee's Report. The above scantlings are intended to apply to pipes for working steam pressures up to 55 lb. per square inch and water pressures up to 200 lb. per square inch. Bolt holes to be ⅛″ larger in diameter than bolts, except for ½″ and ⅝″ bolts where holes should be 1/16″ larger.

British Standard Whitworth Threads.

(See tables pp. 535-537.)

The angle of thread is 55°, and thread is rounded as shown in fig. 241, so that $H = \cdot 9605P$ and $D = \cdot 6403P$, P being the pitch. The circular diameter in the table is twice the minimum radius.

* All tables have been reprinted by permission of the Engineering Standards Committee.

† See Report No. 10 British Standard Tables of Pipe Flanges; published by Crosby Lockwood & Son, price 2s. 6d.

British Standard Whitworth Screw Threads (with sizes of hexagonal nuts and bolt heads).*

Full Diameter.	Number of Threads.	Pitch.	Standard Depth of Thread.	Core Diameter.	Cross Sectional Area at bottom of Thread.	Nut. Distance across Flats.	Nut. Distance across Corners.	Thickness of Bolt Head.
in.	per in.	in.	in.	in.	sq. in.	in.	in.	in.
1/4	20	·0500	·0320	·1860	·0272	·525	·6062	·2187
5/16	18	·0556	·0356	·2414	·0458	·6014	·6944	·2734
3/8	16	·0625	·0400	·2950	·0683	·7094	·8191	·3281
7/16	14	·0714	·0457	·3460	·0940	·8204	·9473	·3828
1/2	12	·0833	·0534	·3933	·1215	·9191	1·0612	·4375
9/16	12	·0833	·0534	·4558	·1632	1·011	1·1674	·4921
5/8	11	·0909	·0582	·5086	·2032	1·101	1·2713	·5468
11/16	11	·0909	·0582	·5711	·2562	1·2011	1·3869	·6015
3/4	10	·1000	·0640	·6219	·3038	1·3012	1·5024	·6562
13/16	10	·1000	·0640	·6844	·3679	1·39	1·6050	·7109
7/8	9	·1111	·0711	·7327	·4216	1·4788	1·7075	·7656
1	8	·1250	·0800	·8399	·5540	1·6701	1·9284	·875
1 1/8	7	·1429	·0915	·9420	·6969	1·8605	2·1483	·9843
1 1/4	7	·1429	·0915	1·0670	·8942	2·0483	2·3651	1·0937
1 3/8	6	·1667	·1067	1·1616	1·0597	2·2146	2·5572	1·2031
1 1/2	6	·1667	·1067	1·2866	1·3001	2·4134	2·7867	1·3125
1 5/8	5	·2000	·1281	1·3689	1·4718	2·5763	2·9748	1·4218
1 3/4	5	·2000	·1281	1·4939	1·7528	2·7578	3·1844	1·5312
2	4·5	·2222	·1423	1·7154	2·3111	3·1491	3·6362	1·75
2 1/4	4	·2500	·1601	1·9298	2·9249	3·546	4·0945	1·9687
2 1/2	4	·2500	·1601	2·1798	3·7318	3·894	4·4964	2·1875
2 3/4	3·5	·2857	·1830	2·3841	4·4641	4·181	4·8278	2·4062
3	3·5	·2857	·1830	2·6341	5·4496	4·531	5·2319	2·625
3 1/4	3·25	·3077	·1970	2·8560	6·4063	4·85	5·6003	2·843
3 1/2	3·25	·3077	·1970	3·1060	7·5769	5·175	5·9755	3·062
3 3/4	3	·3333	·2134	3·3231	8·6732	5·55	6·4085	3·281
4	3	·3333	·2134	3·5731	10·0272	5·95	6·8704	3·5
4 1/2	2·875	·3478	·2227	4·0546	12·9118	6·825	7·8808	3·937
5	2·75	·3636	·2328	4·5343	16·1477	7·8	9·0066	4·375
5 1/2	2·625	·3810	·2439	5·0121	19·7301	8·85	10·2190	4·809
6	2·5	·4000	·2561	5·4877	23·6521	10	11·5470	5·25

Note.—The thickness of nut is always equal to the full diameter of bolt.

* See Report No. 20 British Standard Screw Threads and Report No. 28 British Standard Nuts, Bolt-heads, and Spanners, published by Messrs. Crosby Lockwood and Son, price 2*s*. 6*d*. each.

British Standard Fine Screw Threads.*

Full Diameter.	No. of Threads.	Pitch.	Standard Depth of Thread.	Core Diameter.	Cross Sectional Area at bottom of Thread.
in.	per in.				
$\frac{1}{4}$	25	·0400	·0256	·1988	·0310
$\frac{5}{16}$	22	·0455	·0291	·2543	·0508
$\frac{3}{8}$	20	·0500	·0320	·3110	·076[illegible]
$\frac{7}{16}$	18	·0556	·0356	·3664	·1054
$\frac{1}{2}$	16	·0625	·0400	·4200	·1385
$\frac{9}{16}$	16	·0625	·0400	·4825	·1828
$\frac{5}{8}$	14	·0714	·0457	·5335	·2235
$\frac{11}{16}$	14	·0714	·0457	·5960	·2790
$\frac{3}{4}$	12	·0833	·0534	·6433	·3250
$\frac{13}{16}$	12	·0833	·0534	·7058	·3913
$\frac{7}{8}$	11	·0909	·0582	·7586	·4520
1	10	·1000	·0640	·8719	·5971
$1\frac{1}{8}$	9	·1111	·0711	·9827	·7585
$1\frac{1}{4}$	9	·1111	·0711	1·1077	1·96[illegible]
$1\frac{3}{8}$	8	·1250	·0800	1·2149	1·1593
$1\frac{1}{2}$	8	·1250	·0800	1·3399	1·4100
$1\frac{5}{8}$	8	·1250	·0800	1·4649	1·6854
$1\frac{3}{4}$	7	·1429	·0915	1·5670	2·9285
2	7	·1429	·0915	1·8176	3·5930
$2\frac{1}{4}$	6	·1667	·1067	2·0366	3·2576
$2\frac{1}{2}$	6	·1667	·1067	2·2866	4·1065
$2\frac{3}{4}$	6	·1667	·1067	2·5366	5·0535
3	5	·2000	·1281	2·7439	5·9133
$3\frac{1}{4}$	5	·2000	·1281	2·9939	7·0399
$3\frac{1}{2}$	4·5	·2222	·1423	3·2154	8·1201
$3\frac{3}{4}$	4·5	·2222	·1423	3·4654	9·4319
4	4·5	·2222	·1423	3·7154	10·8418
$4\frac{1}{2}$	4	·2500	·1601	4·1798	13·7215
5	4	·2500	·1601	4·6798	17·2006
$5\frac{1}{2}$	3·5	·2857	·1830	5·1341	20·7023
6	3·5	·2857	·1830	5·6341	24·9310

* See Report No. 20 British Standard Screw Threads, published by essrs. Crosby Lockwood & Son, price 2s. 6d.

British Standard Pipe Threads.*

Nominal Bore of Tube.	Approximate outside Diameter of B Pack Tube.	Gauge Diameter, top of Thread.	Depth of Thread.	Core Diameter.	Number of Threads.
in.	in.	in.	in.	in.	per in.
$\frac{1}{8}$	$\frac{13}{32}$	·383	·0230	·337	28
$\frac{1}{4}$	$\frac{17}{32}$	·518	·0335	·451	19
$\frac{3}{8}$	$\frac{11}{16}$	·656	·0335	·589	19
$\frac{1}{2}$	$\frac{27}{32}$	·825	·0455	·734	14
$\frac{5}{8}$	$\frac{15}{16}$	·902	·0455	·811	14
$\frac{3}{4}$	$1\frac{1}{16}$	1·041	·0455	·950	14
$\frac{7}{8}$	$1\frac{7}{32}$	1·189	·0455	1·098	14
1	$1\frac{11}{32}$	1·309	·0580	1·193	11
$1\frac{1}{4}$	$1\frac{11}{16}$	1·650	·0580	1·534	11
$1\frac{1}{2}$	$1\frac{29}{32}$	1·882	·0580	1·766	11
$1\frac{3}{4}$	$2\frac{5}{32}$	2·116	·0580	2·000	11
2	$2\frac{3}{8}$	2·347	·0580	2·231	11
$2\frac{1}{4}$	$2\frac{5}{8}$	2·587	·0580	2·471	11
$2\frac{1}{2}$	3	2·960	·0580	2·844	11
$2\frac{3}{4}$	$3\frac{1}{4}$	3·210	·0580	3·094	11
3	$3\frac{1}{2}$	3·460	·0580	3·344	11
$3\frac{1}{4}$	$3\frac{3}{4}$	3·700	·0580	3·584	11
$3\frac{1}{2}$	4	3·950	·0580	3·834	11
$3\frac{3}{4}$	$4\frac{1}{4}$	4·200	·0580	4·084	11
4	$4\frac{1}{2}$	4·450	·0580	4·334	11
$4\frac{1}{2}$	5	4·950	·0580	4·834	11
5	$5\frac{1}{2}$	5·450	·0580	5·334	11
$5\frac{1}{2}$	6	5·950	·0580	5·834	11
6	$6\frac{1}{2}$	6·450	·0580	6·334	11
7	$7\frac{1}{2}$	7·450	·0640	7·322	10
8	$8\frac{1}{2}$	8·450	·0640	8·322	10
9	$9\frac{1}{2}$	9·450	·0640	9·322	10
10	$10\frac{1}{2}$	10·450	·0640	10·322	10
11	$11\frac{1}{2}$	11·450	·0800	11·290	8
12	$12\frac{1}{2}$	12·450	·0800	12·290	8
13	$13\frac{3}{4}$	13·680	·0800	13·520	8
14	$14\frac{3}{4}$	14·680	·0800	14·520	8
15	$15\frac{3}{4}$	15·680	·0800	15·520	8
16	$16\frac{3}{4}$	16·680	·0800	16·520	8
17	$17\frac{3}{4}$	17·680	·0800	17·520	8
18	$18\frac{3}{4}$	18·680	·0800	18·520	8

Length of screw on pipe end = $\sqrt[5]{d^2} - \frac{1}{8}''$ (d = nominal bore).

* See Report No. 21 British Standard Pipe Threads for Iron or Steel Pipes and Tubes, published by Messrs. Crosby Lockwood & Son, price 2*s.* 6*d.*

SHIP FITTINGS.

Admiralty Lengths of Chain Cables.

A cable consists of eight lengths of 12½ fathoms each, with a joining shackle to each length.

Hawse Pipes and Deck Pipes.

Hawse pipes should be 10 diameters, and deck pipes 8 diameters of the chain cable.

Admiralty Proportions of Chains, Cables, etc.

Stud Link Chain.

Extreme length	= 6 times diameter of cable.
,, width	= 3·6 ,, ,,
Diameter of stay pin at middle	= ·6 ,, ,,
,, ,, ends	= diameter of cable.

Type of Chain.	*Open Link.*	*Rigging.*	*Cat.*
Extreme length—			
Diameter of chain .	6	5	4⅗
Extreme width—			
Diameter of chain .	3·6	3¼	3⅓

Mild Steel Thimbles (Fig. 241A).						
Size of Rope.	**A.**	**B.**	**C.**	**D.**	**E.**	**F.**
1	[illegible]	$\frac{7}{16}$	2⅝	$\frac{3}{16}$	1⅝	$\frac{7}{16}$
1¼ and 1½	1$\frac{5}{16}$	$\frac{11}{16}$	3⅜	$\frac{5}{16}$	2⅜	$\frac{11}{16}$
1¾ ,, 2	1$\frac{11}{16}$	$\frac{15}{16}$	4⅜	$\frac{7}{16}$	3	$\frac{15}{16}$
2¼ ,, 2½	2⅛	1$\frac{1}{16}$	5⅜	½	3⅝	1$\frac{1}{16}$
2¾ ,, 3	2$\frac{7}{16}$	1$\frac{3}{16}$	6⅜	$\frac{9}{16}$	4⅜	1¼
3½	2⅝	1⅜	7⅝	⅝	5¼	1$\frac{7}{16}$
4	3$\frac{5}{16}$	1½	9⅜	$\frac{13}{16}$	6¼	1$\frac{11}{16}$
4½	3¾	2	10¼	⅞	6⅞	1⅞
5	4¼	2$\frac{3}{32}$	11	1	7¾	2
5½	4⅝	2⅜	12¾	1⅛	8$\frac{9}{16}$	2$\frac{5}{16}$
6	5	2$\frac{11}{16}$	14	1$\frac{3}{16}$	9½	2½
6½	5⅜	2$\frac{15}{16}$	15½	1¼	10½	2¾

All dimensions in inches ; G = $\frac{5}{32}$" up to 3" rope, ¼" above.

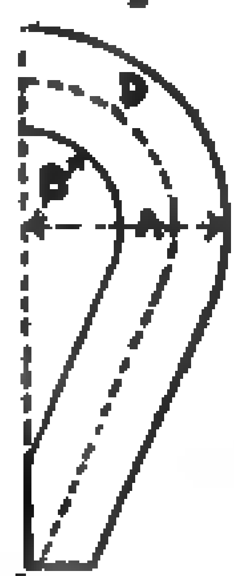


Fig. 241A.

Slips for Chain Rigging, etc.

Fig. 242.

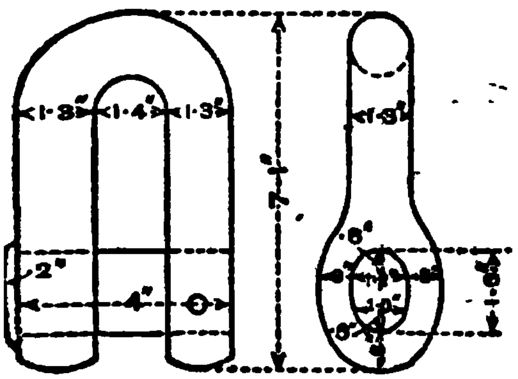


Fig. 243.

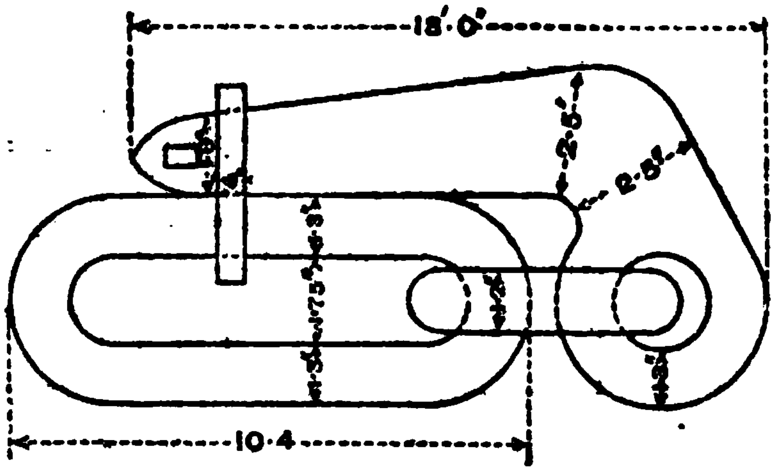
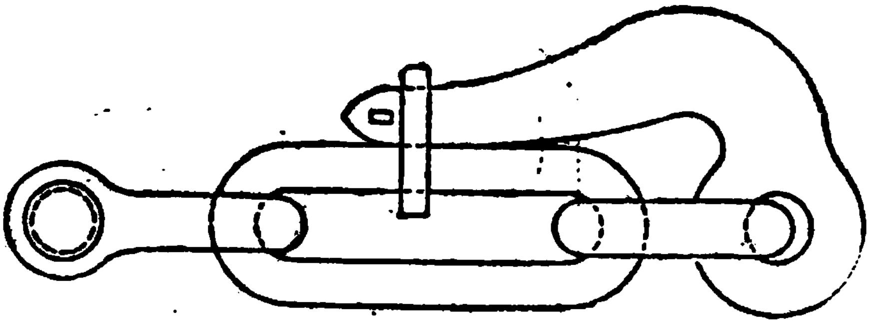


Fig. 244.



Sizes of Iron in Inches for Straight and Monkey-tailed Slips. (Figs. 242, 243, 244.)

Size of Chain.	Straight Slip.	Monkey Slip.	Short Link.	Long Link.	Buckler.	Shackle.	Size of Chain.	Straight Slip.	Monkey Slip.	Short Link.	Long Link.	Buckler.	Shackle.	Tons (Proof Load).
$\frac{3}{8}$	$\frac{7}{8}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	1	$1\frac{1}{8}$	$\frac{5}{8}$	$1\frac{1}{8}$	$8\frac{7}{8}$
$\frac{7}{16}$ and $\frac{1}{2}$	1	$1\frac{1}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{3}{4}$	1	$1\frac{7}{8}$	2	$1\frac{1}{8}$	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	11
$\frac{9}{16}$ and $\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{4}$, $\frac{7}{8}$	$1\frac{1}{8}$	2	$2\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$\frac{7}{8}$	$1\frac{3}{8}$	$13\frac{1}{4}$
$\frac{11}{16}$ and $\frac{3}{4}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{1}{2}$	1	$1\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	$15\frac{3}{4}$

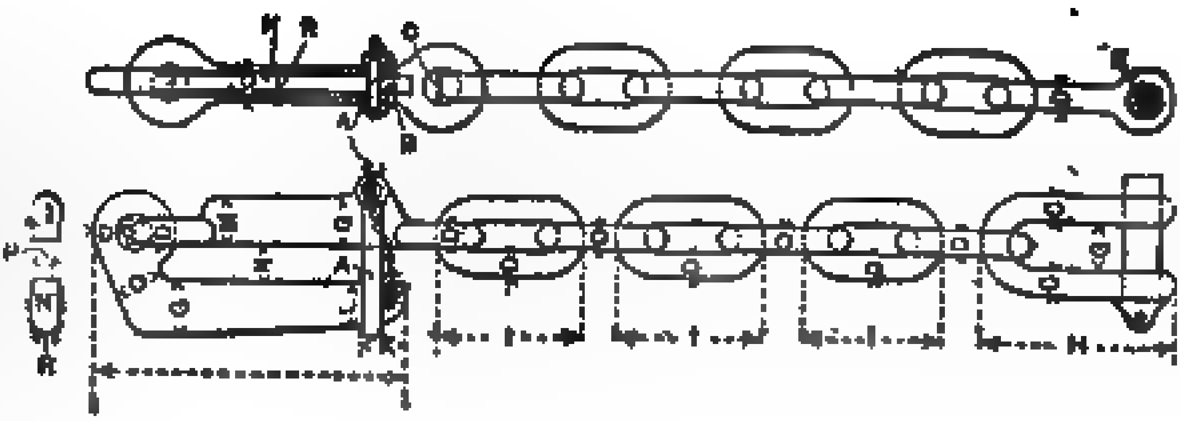
Note.—The pins of the shackles are $\frac{1}{8}$" larger than iron of shackle.

Blake's Stoppers.

Fig. 245.

A	·5
B	·38
C	·875
D	·75
E	1·0
F	1·25
G	1·5
H	3·0
I	4·3
J	3·45
K	1·65
L	1·31
M	1·4
N	1·1
O	1·6
P	·63
Q	1·9
R	·76

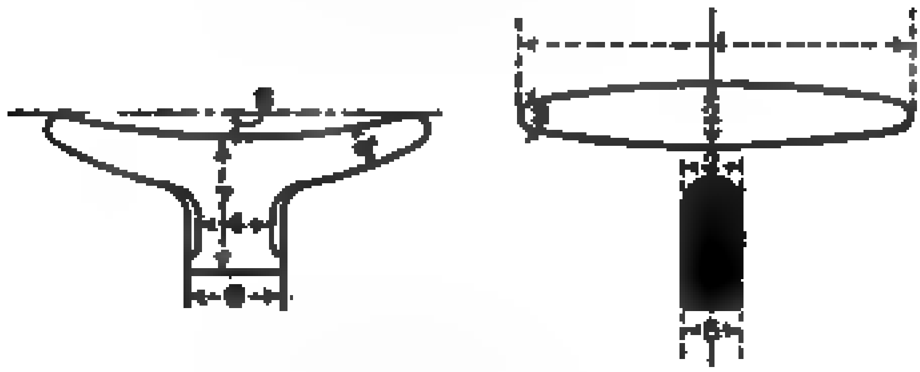
Fig. 246.



Sizes of Blake's Stopper. (Fig. 245.)

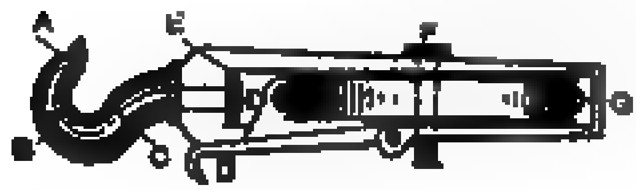
Size of Cable	Dimensions													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
1	$1\frac{7}{16}$	$1\frac{3}{8}$	$1\frac{1}{4}$	$\frac{7}{8}$	$7\frac{3}{4}$	$2\frac{5}{16}$	2	$\frac{5}{8}$	$\frac{1}{2}$	$2\frac{13}{16}$	6	$3\frac{3}{4}$	$\frac{9}{16}$	$2\frac{1}{4}$
$1\frac{1}{8}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{3}{8}$	$\frac{15}{16}$	$8\frac{5}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$\frac{11}{16}$	[illegible]	$3\frac{1}{16}$	$6\frac{3}{4}$	$3\frac{15}{16}$	$\frac{5}{8}$	$2\frac{7}{16}$
$1\frac{1}{4}$	$1\frac{13}{16}$	$1\frac{11}{16}$	$1\frac{1}{2}$	1	$9\frac{3}{8}$	3	$2\frac{1}{2}$	$\frac{3}{4}$	[illegible]	$3\frac{5}{16}$	$7\frac{1}{2}$	$4\frac{3}{8}$	$\frac{11}{16}$	$2\frac{13}{16}$
$1\frac{3}{8}$	2	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{1}{8}$	$10\frac{7}{16}$	$3\frac{5}{16}$	$2\frac{3}{4}$	$\frac{13}{16}$	[illegible]	$4\frac{1}{16}$	$8\frac{1}{4}$	$4\frac{13}{16}$	$\frac{3}{4}$	3
$1\frac{1}{2}$	$2\frac{3}{16}$	2	$1\frac{3}{4}$	$1\frac{3}{16}$	$11\frac{1}{2}$	$3\frac{5}{8}$	3	$\frac{7}{8}$	[illegible]	$4\frac{3}{8}$	9	$5\frac{1}{4}$	$\frac{13}{16}$	$3\frac{1}{4}$
$1\frac{5}{8}$	$2\frac{3}{8}$	$2\frac{3}{16}$	$1\frac{13}{16}$	$1\frac{5}{16}$	$12\frac{9}{16}$	$3\frac{15}{16}$	$3\frac{1}{4}$	1	[illegible]	$4\frac{5}{8}$	$9\frac{3}{4}$	$5\frac{11}{16}$	$\frac{7}{8}$	$3\frac{1}{2}$
$1\frac{3}{4}$	$2\frac{9}{16}$	$2\frac{3}{8}$	$2\frac{1}{8}$	$1\frac{7}{16}$	$13\frac{5}{8}$	$4\frac{1}{4}$	$3\frac{1}{2}$	$1\frac{1}{16}$	[illegible]	$5\frac{1}{8}$	$10\frac{1}{2}$	$6\frac{1}{8}$	$\frac{15}{16}$	$3\frac{3}{4}$
$1\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{1}{2}$	$14\frac{11}{16}$	$4\frac{9}{16}$	$3\frac{3}{4}$	$1\frac{1}{8}$	[illegible]	$5\frac{3}{8}$	$11\frac{1}{4}$	$6\frac{9}{16}$	1	4
2	$2\frac{7}{8}$	$2\frac{11}{16}$	$2\frac{3}{8}$	$1\frac{5}{8}$	15	$4\frac{7}{8}$	4	$1\frac{3}{16}$	[illegible]	$5\frac{5}{8}$	12	7	$1\frac{1}{8}$	$4\frac{1}{4}$
$2\frac{1}{8}$	$3\frac{1}{16}$	$2\frac{13}{16}$	$2\frac{7}{16}$	$1\frac{11}{16}$	$15\frac{13}{16}$	$5\frac{3}{16}$	$4\frac{1}{4}$	$1\frac{1}{4}$	[illegible]	$6\frac{1}{8}$	$12\frac{3}{4}$	$7\frac{7}{16}$	$1\frac{3}{16}$	$4\frac{1}{2}$
$2\frac{1}{4}$	$3\frac{1}{4}$	3	$2\frac{11}{16}$	$1\frac{13}{16}$	$16\frac{7}{8}$	$5\frac{1}{2}$	$4\frac{1}{2}$	$1\frac{5}{16}$	[illegible]	$6\frac{3}{8}$	$13\frac{1}{2}$	$7\frac{7}{8}$	$1\frac{1}{4}$	$4\frac{3}{4}$
$2\frac{3}{8}$	$3\frac{7}{16}$	$3\frac{3}{16}$	$2\frac{13}{16}$	$1\frac{15}{16}$	$17\frac{15}{16}$	$5\frac{13}{16}$	$4\frac{3}{4}$	$1\frac{3}{8}$	[illegible]	$6\frac{11}{16}$	$14\frac{1}{4}$	$8\frac{5}{16}$	$1\frac{5}{16}$	$5\frac{1}{16}$
$2\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{5}{16}$	3	2	$18\frac{3}{4}$	6	5	$1\frac{7}{16}$	[illegible]	$7\frac{1}{16}$	15	$8\frac{3}{4}$	$1\frac{3}{8}$	$5\frac{1}{4}$
$2\frac{[illegible]}{16}$	$3\frac{13}{16}$	$3\frac{7}{16}$	$3\frac{3}{16}$	$2\frac{1}{16}$	$19\frac{1}{16}$	$6\frac{1}{4}$	$5\frac{1}{4}$	$1\frac{9}{16}$	[illegible]	$7\frac{1}{4}$	$15\frac{3}{4}$	9	$1\frac{7}{16}$	$5\frac{1}{2}$

FIG. 247.—WOOD BELAYING CLEAT.



SNATCH BLOCK BINDINGS.

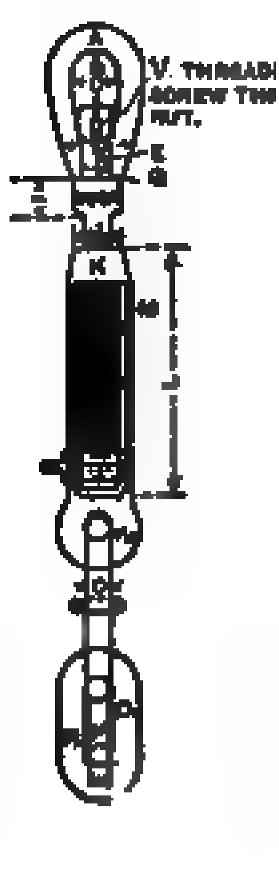
FIG. 248.



RIGGING SLIPS AND SCREWS.

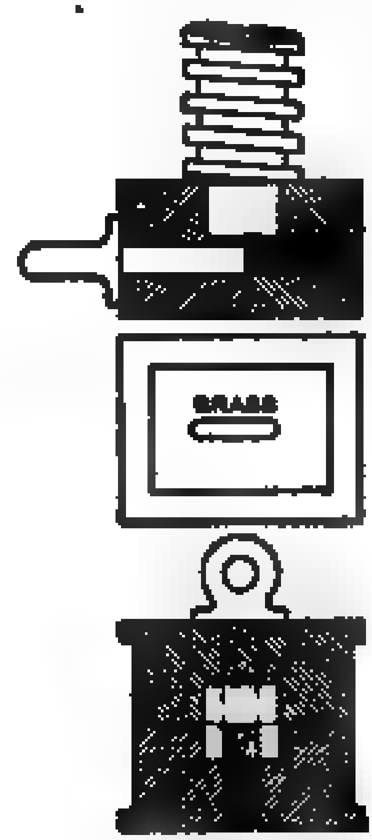
(p. 544.)

FIG. 249.



FITTINGS FOR LOWER PART OF SCREWS TO PREVENT THEM WORKING LOOSE.

FIG. 250.



These fittings are all in proportion to the steel wire rope.

DIMENSIONS IN INCHES OF WOOD BELAYING CLEATS.
(*See Sketch*, fig. 247.)

1	2	3	4	5	6	7	8	[illegible]
8	1	7/8	2 1/2	1 3/8	2 3/4	2 1/8	3/8	1
10	1 3/8	1 1/16	3 1/4	1 7/8	4	3 3/8	1/2	1 1/4
12	1 [illegible]	1 1/4	4	2 1/8	4 1/2	3 5/8	[illegible]	[illegible]
14	1 7/8	1 3/8	4 1/2	2 1/4	5	4	[illegible]	1 7/8
16	2 [illegible]	1 1/2	5 1/4	2 5/8	5 3/4	4 1/2	1	2
18	2 [illegible]	1 5/8	6	3	6 1/4	5	1 1/8	2 1/4
20	2 [illegible]	1 3/4	7	3 1/4	6 3/4	5 3/8	1 1/4	2 1/2
22	2 7/8	2	7 1/2	3 5/8	7 1/2	6 1/4	1 3/8	2 7/8
24	3 [illegible]	2 1/8	8	4	8	6 [illegible]	1 [illegible]	3 [illegible]
26	3 [illegible]	2 1/4	8 1/2	4 1/4	9	6 [illegible]	1 [illegible]	3 [illegible]
28	3 5/8	2 [illegible]	9 1/4	4 5/8	9 5/8	7	1 [illegible]	3 [illegible]
30	4	2 [illegible]	10	5	10 1/4	7 1/4	1 [illegible]	3 [illegible]
32	4 1/2	3	10 1/2	5 3/8	10 3/4	7 3/4	1 [illegible]	3 [illegible]

DIMENSIONS IN INCHES OF SNATCH BLOCK BINDINGS.
(*See Sketch*, fig. 248.)

Size of Block	A	B	C	D	E	F	G	Length of Hook	Size of Pin
8	[illegible]	[illegible]	1 1/4	[illegible]	[illegible]	[illegible]	1 × 1/2	8	[illegible]
9	[illegible]	[illegible]	1 7/16	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	9	[illegible]
10	[illegible]	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	10	[illegible]
11	[illegible]	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	11	[illegible]
12	[illegible]	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	11 1/2	1
13	1	[illegible]	1 [illegible]	[illegible]	2 [illegible]	[illegible]	1 [illegible] × [illegible]	12 [illegible]	1 1/16
14	1	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	13	1 [illegible]
15	1 [illegible]	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	14	1 [illegible]
16	1 [illegible]	[illegible]	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	15	1 [illegible]
17	1 [illegible]	2	1 [illegible]	[illegible]	[illegible]	[illegible]	1 [illegible] × [illegible]	15 1/2	1 [illegible]
18	1 [illegible]	[illegible]	2	4	[illegible]	[illegible]	2 × [illegible]	16	1 [illegible]
19	1 [illegible]	[illegible]	2 [illegible]	4	[illegible]	[illegible]	2 [illegible] × [illegible]	17	1 [illegible]
20	1 [illegible]	[illegible]	2 [illegible]	4	[illegible]	[illegible]	2 [illegible] × [illegible]	18	1 [illegible]
21	1 [illegible]	[illegible]	2 [illegible]	4	[illegible]	[illegible]	2 [illegible] × [illegible]	19	1 [illegible]
22	1 [illegible]	[illegible]	2 [illegible]	4	3	[illegible]	2 [illegible] × [illegible]	20	1 [illegible]
23	1 [illegible]	[illegible]	2 [illegible]	5	[illegible]	[illegible]	2 [illegible] × [illegible]	21	1 [illegible]
24	1 [illegible]	[illegible]	2 [illegible]	5	[illegible]	[illegible]	2 [illegible] × [illegible]	22	1 [illegible]
25	1 [illegible]	[illegible]	2 [illegible]	6	[illegible]	[illegible]	2 [illegible] × [illegible]	23	1 [illegible]
26	1 [illegible]	[illegible]	3	6	[illegible]	[illegible]	2 [illegible] × [illegible]	24	1 [illegible]

(FIG. 249, p. 542.)

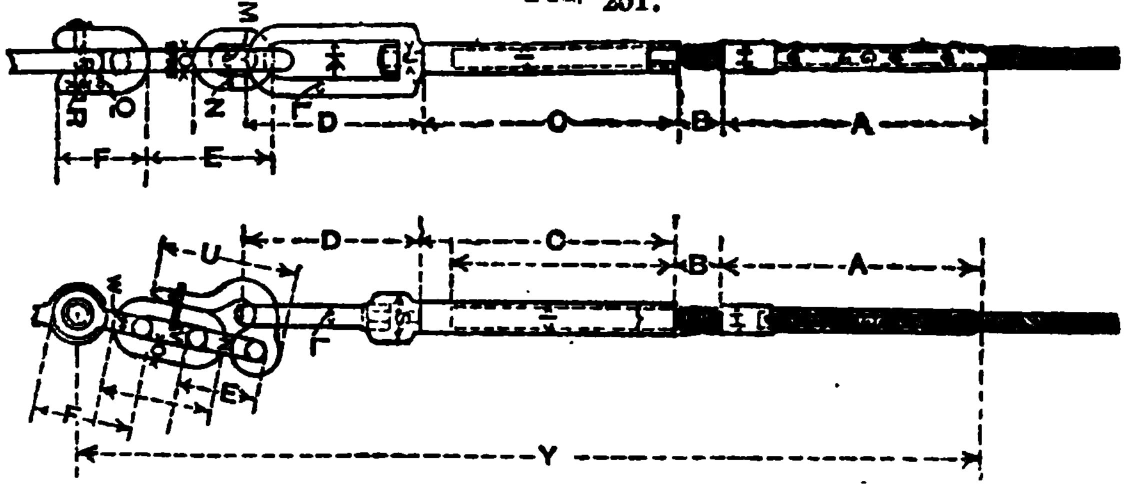
	For $2\frac{1}{2}''$ Steel Wire		For $2\frac{1}{4}''$ Steel Wire		For $2''$ Steel Wire		For $1\frac{1}{4}''$ Steel Wire	
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.
A	1	6	1	$5\frac{5}{8}$	1	5	1	$4\frac{7}{8}$
B		$3\frac{1}{4}$		$3\frac{1}{8}$		$3\frac{1}{8}$		3
C	1	$5\frac{1}{2}$	1	$5\frac{1}{8}$	1	$4\frac{3}{4}$	1	$4\frac{5}{8}$
D	1	$0\frac{3}{8}$		$11\frac{3}{8}$		$11\frac{3}{4}$		$11\frac{1}{8}$
E		$4\frac{7}{8}$		$4\frac{3}{8}$		$4\frac{3}{8}$		$4\frac{1}{8}$
F		$6\frac{3}{8}$		6		6		$5\frac{3}{8}$
G		$1\frac{3}{8}$		$1\frac{1}{4}$		$1\frac{1}{8}$		$\frac{7}{8}$
H		$1\frac{3}{4}$		$1\frac{5}{8}$		$1\frac{1}{2}$		$1\frac{1}{8}$
I		$1\frac{7}{8}$		$1\frac{3}{4}$		$1\frac{5}{8}$		$1\frac{3}{8}$
J		$1\frac{1}{8}$		$\frac{15}{16}$		$\frac{7}{8}$		$\frac{3}{4}$
K		$2\frac{1}{8}$		2		2		$1\frac{7}{8}$
L		$1\frac{1}{8}$		$\frac{7}{8}$		$\frac{7}{8}$		$\frac{3}{4}$
M		$1\frac{3}{8}$		$1\frac{1}{8}$		$1\frac{3}{8}$		$1\frac{1}{8}$
N		$1\frac{1}{16}$		$\frac{7}{8}$		$\frac{3}{4}$		$\frac{3}{4}$
O		$1\frac{1}{16}$		$\frac{7}{8}$		$\frac{3}{4}$		$\frac{3}{4}$
P		$1\frac{5}{8}$		$1\frac{5}{8}$		$1\frac{1}{8}$		$1\frac{1}{8}$
Q		$1\frac{1}{8}$		1		$\frac{7}{8}$		$\frac{3}{4}$
R		$1\frac{1}{4}$		$1\frac{1}{8}$		1		$\frac{7}{8}$
S		$3\frac{1}{4}$		$2\frac{7}{8}$		$2\frac{5}{8}$		$2\frac{3}{8}$
T		$1\frac{3}{4}$		$1\frac{3}{8}$		$1\frac{1}{2}$		$1\frac{3}{8}$
U		$9\frac{3}{4}$		$9\frac{1}{4}$		$9\frac{1}{8}$		9
V		$1\frac{5}{8}$		$1\frac{5}{8}$		$1\frac{5}{8}$		$1\frac{5}{8}$
W		$1\frac{1}{8}$		1		$\frac{7}{8}$		$\frac{3}{4}$
X		$1\frac{1}{8}$		1		$\frac{7}{8}$		$\frac{3}{4}$
Y	5	$2\frac{1}{2}$	5	1	4	$11\frac{1}{2}$	4	11
Screw		$1\frac{3}{8}$ dia.		$1\frac{1}{4}$ dia.		$1\frac{1}{8}$ dia.		$\frac{7}{8}$ dia.

STOWAGE OF CHAIN CABLE
(CUBIC FEET PER 100 FATHOMS).

Diameter in inches	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$
Cubic feet . .	14	20	27	35	44	55	66
Diameter in inches	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$
Cubic feet . .	80	93	105	130	160	190	230
Diameter in inches	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$
Cubic feet . .	270	315	355	395	480	560	650

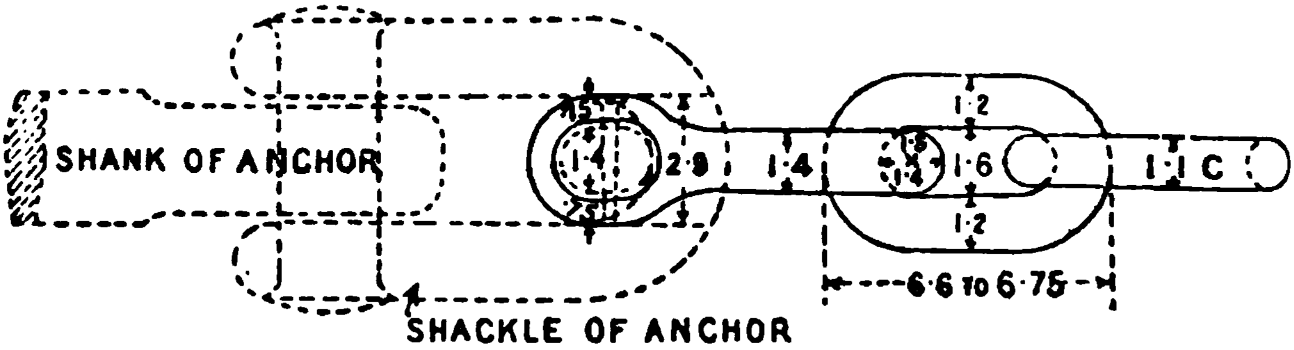
SCREWS, SLIPS, &c., FOR SETTING UP SHROUDS AND BACKSTAYS.

FIG. 251.



	For 7 & $6\frac{1}{2}$ Steel Wire	For 6 & $5\frac{1}{2}$ Steel Wire	For 5 & $4\frac{1}{2}$ Steel Wire	For 4 & $3\frac{1}{2}$ Steel Wire	For 3 & $2\frac{1}{2}$ Steel Wire	For 2 & $1\frac{1}{2}$ Steel Wire
	Proof Strain 44 Tons	Proof Strain 36 Tons	Proof Strain 24 Tons	Proof Strain 18 Tons	Proof Strain 12 tons	Proof Strain 6 Tons
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
A	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{3}{4}$
B	$4\frac{1}{2}$	$4\frac{1}{4}$	$3\frac{1}{2}$	$2\frac{1}{2}$	2	$1\frac{1}{2}$
C	$4\frac{1}{8}$	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{3}{8}$	$1\frac{7}{8}$	$1\frac{3}{8}$
D	$2\frac{5}{8}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{8}$	1
E	$2\frac{5}{8}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{3}{8}$	1
F	6	$5\frac{1}{2}$	$4\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{1}{8}$	$2\frac{5}{8}$
G	$2\frac{5}{8}$	$2\frac{3}{8}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{3}{8}$	1
H	4	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{1}{2}$	2	$1\frac{1}{2}$
I	$2\frac{5}{8}$	$2\frac{3}{8}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{3}{8}$	1
J	4	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{1}{2}$	2	$1\frac{1}{2}$
K	$3\frac{1}{4}$	3	$2\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{4}$
L	19	17	15	$13\frac{1}{2}$	12	$10\frac{1}{2}$
M	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$
N	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{5}{8}$
O	$2\frac{1}{8}$	2	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{7}{8}$
P	$2\frac{1}{4} \times 5\frac{5}{8}$	$2\frac{1}{8} \times 5$	$2 \times 4\frac{1}{2}$	$1\frac{5}{8} \times 3\frac{5}{8}$	$1\frac{3}{8} \times 3\frac{1}{2}$	$1 \times 2\frac{1}{4}$
Q	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$
R	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{3}{4}$
S	$2\frac{7}{8}$	$2\frac{5}{8}$	$2\frac{3}{8}$	2	$1\frac{5}{8}$	$1\frac{1}{4}$
T	$2\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$
U	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{3}{4}$
V	$3\frac{3}{4}$	$3\frac{1}{2}$	$3\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{1}{4}$
W	$20 \times 1\frac{7}{8}$	$18\frac{1}{4} \times 1\frac{3}{4}$	$16\frac{1}{2} \times 1\frac{5}{8}$	$13 \times 1\frac{5}{16}$	$11\frac{1}{2} \times 1\frac{1}{8}$	$8 \times \frac{7}{8}$
X	1	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$
Y	$2\frac{1}{2} \times 11$	$2\frac{3}{8} \times 10\frac{1}{2}$	$2\frac{1}{8} \times 9\frac{3}{4}$	$1\frac{3}{4} \times 7\frac{7}{8}$	$1\frac{3}{8} \times 7\frac{1}{2}$	$1\frac{1}{8} \times 5$
Screw {	$2\frac{5}{8}$ dia. $\frac{1}{2}$ pitch	$2\frac{3}{8}$ dia. $\frac{1}{2}$ pitch	$2\frac{1}{8}$ dia $\frac{3}{8}$ pitch	$1\frac{3}{4}$ dia. $\frac{3}{8}$ pitch	$1\frac{3}{8}$ dia. $\frac{1}{4}$ pitch	1 dia. $\frac{1}{4}$ pitch
Z	$2\frac{3}{4}$	$2\frac{5}{8}$	$2\frac{3}{8}$	2	$1\frac{3}{8}$	$1\frac{1}{4}$

FIG. 252.



A = Anchor shackle; B = End link of cable (without stud); C = Enlarged link; X = Tinned steel pin secured with lead pellet. Unit = size of cable.

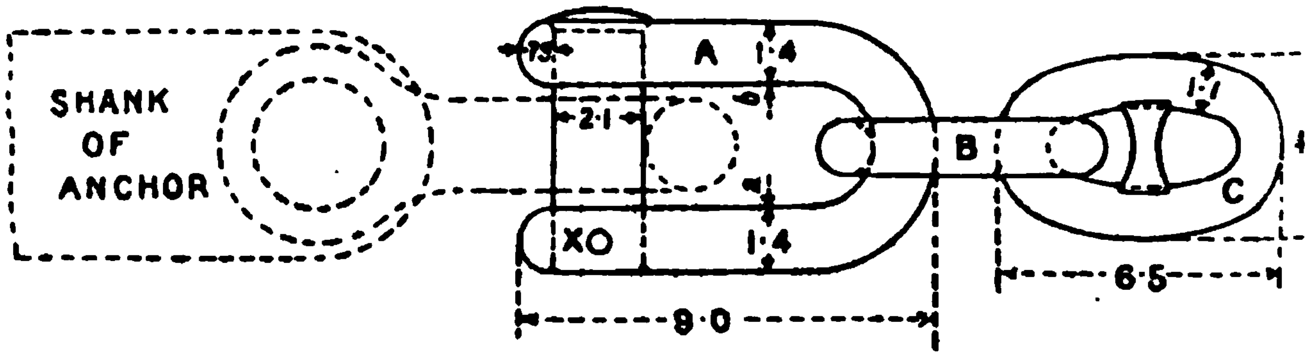
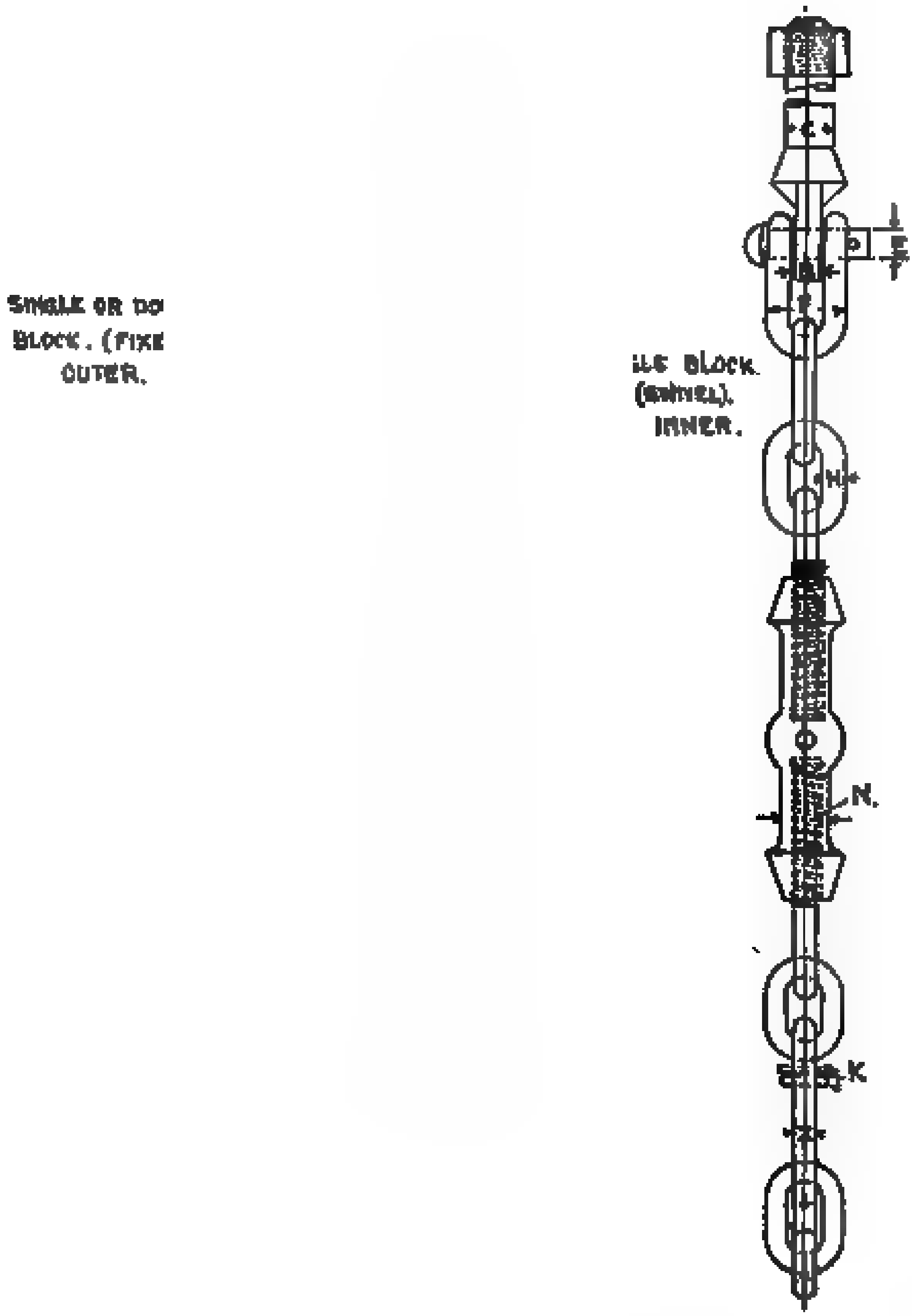


TABLE OF DIMENSIONS OF CROSSHEADS AND SCREW SLIPS FOR BOATS' DAVITS. (Fig. 253.)			
	32 ft. Steam Boat 36 ft. Sailing Pinnace 32-30 ft. Sailing Pinnace	27-28 ft. Steam Cutter 34-25 ft. Cutter	32 ft. Gig and other Small Boats
	Inches	Inches	Inches
A	12¾	12½	10½
A_2	8¾	8½	8½
A_3	5	4¼	4
a	1½	1⅜	1
B	1⅝	1¼	1⅛
C	2½	2	1⅜
D	6	5½	5
E	1½	1⅜	1¼
F	4	3⅜	3¼
G	1¼	1⅜	1
*H	1⅝	1	⅞
I	1⅝	1½	1
J	3½ × 1½	3½ × 1	3¼ × ⅞
K	1½ diam., ⅝ pitch	1¼ diam., 5-16ths pitch	1 diam., ¼ pitch
L	2¼	2	1¾
M	12	12	12
N	3¼ × 3¼	2 × ⅝	1¾ × ½
O	2¼	2	1¼
P	9¾	9½	9
*Q	5½ × 4 × 1½	5 × 3¾ × 1	4½ × 3 × ⅞
R	10 × 4½ × 1¾	9 × 3¾ × 1½	8 × 3½ × 1
S	12	11	9½
T	2½	2¼	2
U	2¼	1¾	1¼
V	6	5	4
W	1¾	1½	1¼
X	½ link	7-16ths link	⅜ link
Y	1¼	1½	1
Z	1¼	1⅜	1

* See note on page 547.



Note.—Steam boats and 36 feet sailing pinnaces, 1 single and 1 double block, 6½ inches diameter.

30 feet and 32 feet sailing pinnaces, 1 single and 1 double block, 8½ inches diameter.

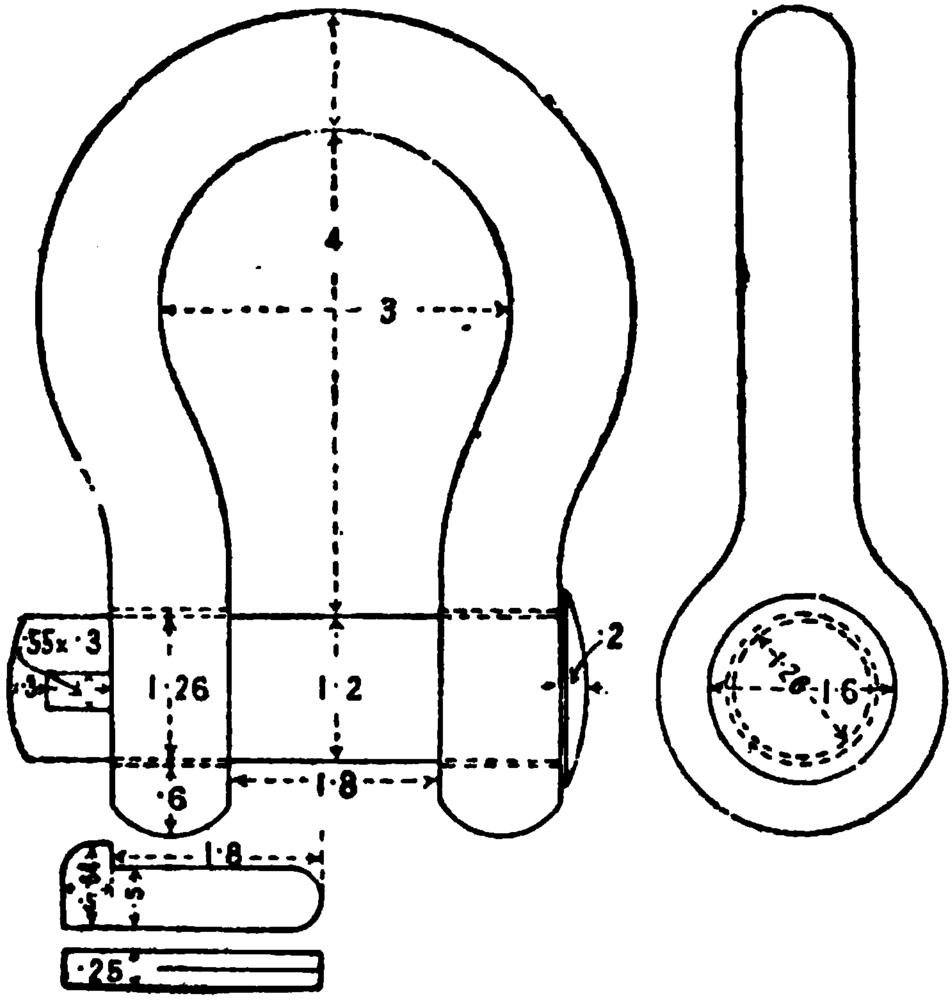
34 feet and 25 feet cutters, 2 single blocks, 8½ inches diameter.

32 feet gig and smaller boats, 2 single blocks, 6½ inches diameter.

* The number of links to be arranged so that the boat may be turned in while suspended by the screw-slip.

Bow Shackle with Forelock.

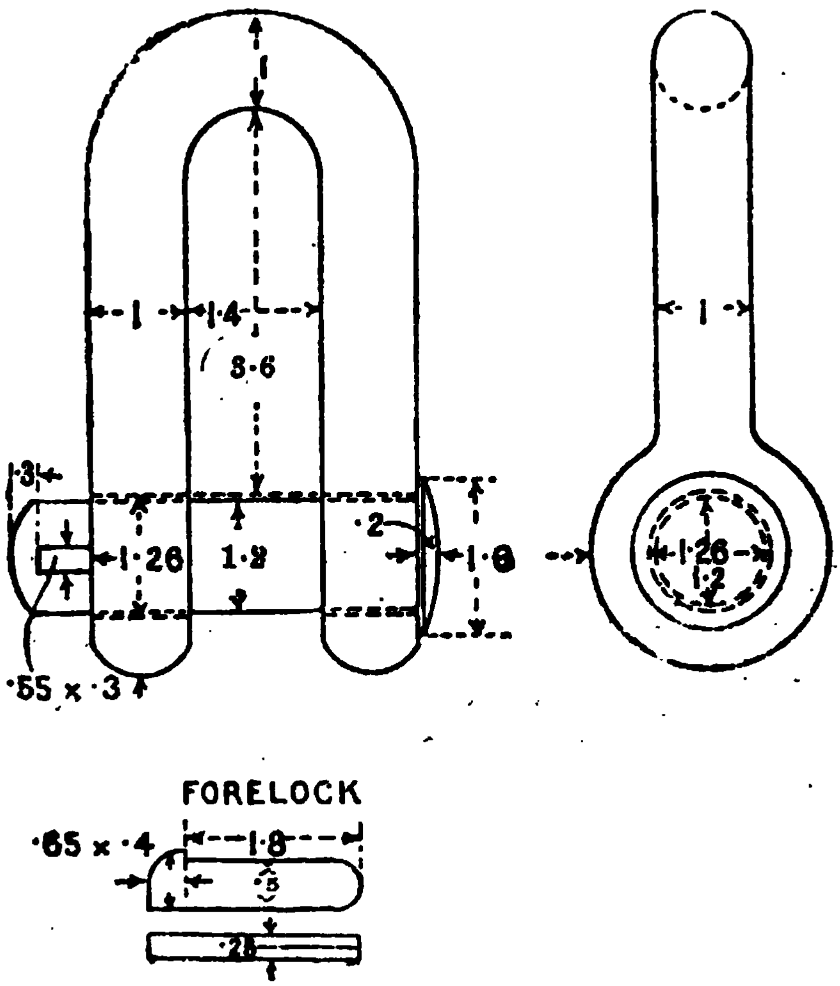
Fig. 254.



Unit in Inches.	Proof Load in Tons.
$\frac{1}{4}$	$\frac{1}{4}$
$\frac{3}{8}$	$\frac{5}{8}$
$\frac{1}{2}$	$1\frac{1}{4}$
$\frac{5}{8}$	2
$\frac{3}{4}$	$2\frac{7}{8}$
$\frac{7}{8}$	4
1	5
$1\frac{1}{8}$	$6\frac{3}{8}$
$1\frac{1}{4}$	$7\frac{7}{8}$
$1\frac{3}{8}$	$9\frac{1}{2}$
$1\frac{1}{2}$	$11\frac{1}{4}$
$1\frac{5}{8}$	$13\frac{1}{2}$
$1\frac{3}{4}$	$15\frac{3}{8}$
$1\frac{7}{8}$	$17\frac{5}{8}$
2	20
$2\frac{1}{2}$	$31\frac{1}{4}$

Straight Rigging Shackle.

Fig. 255.

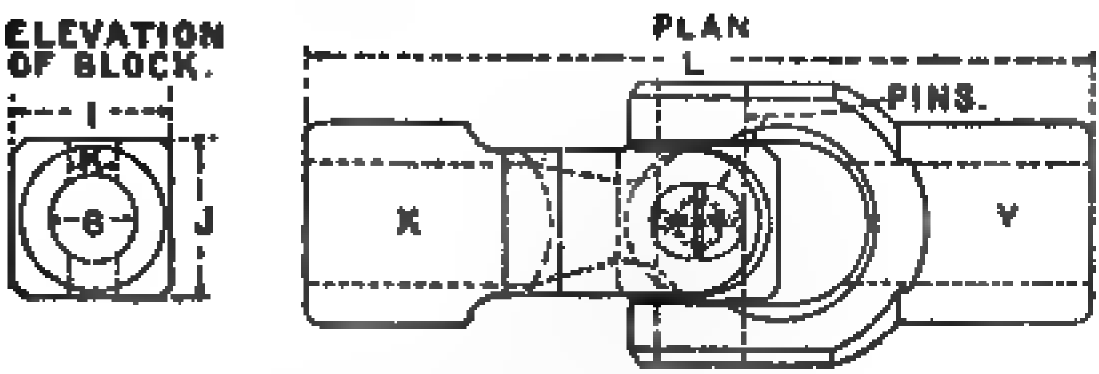


Shackle Diam. in Inches.	Proof Load in Tons.
$\frac{1}{4}$	$\frac{5}{8}$
$\frac{3}{8}$	$1\frac{1}{4}$
$\frac{1}{2}$	$2\frac{1}{4}$
$\frac{5}{8}$	$3\frac{1}{2}$
$\frac{3}{4}$	5
$\frac{7}{8}$	$6\frac{7}{8}$
1	9
$1\frac{1}{8}$	$11\frac{3}{8}$
$1\frac{1}{4}$	14
$1\frac{3}{8}$	17
$1\frac{1}{2}$	$20\frac{1}{4}$

Fig. 256.

Fork "X" Fork "Y"

SIDE FRONT SIDE FRONT



Dimensions (all in inches).															
Diam. of rod.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.	K.	L.	M.	N.	O.
1	3½	1⅜	1⅝	1	[illegible]	½	⅝	1⅝	1⅛	1⅛	⅝	7	2	1½	$\frac{9}{16}$
1⅛	3⅝	1⅜	1⅞	1⅛	1¼	$\frac{9}{16}$	¾	1¾	1⅛	1⅛	⅝	7¼	2	1$\frac{9}{16}$	⅝
1¼	4	1½	2$\frac{1}{16}$	1¼	1⅜	⅝	⅞	2	1⅜	1⅜	½	8	2$\frac{7}{16}$	1⅝	$\frac{11}{16}$
1⅜	4½	1⅝	2⅜	1⅜	1½	⅝	$\frac{15}{16}$	2¼	1½	1½	$\frac{9}{16}$	9	2$\frac{9}{16}$	2¼	$\frac{11}{16}$
1½	5½	1$\frac{13}{16}$	2⅝	1½	1$\frac{11}{16}$	$\frac{11}{16}$	1	2⅝	1$\frac{11}{16}$	1$\frac{11}{16}$	⅝	10½	2⅞	2⅞	¾

GENERAL FORM OF BLOCKS FOR ANCHOR GEAR.

FIG. 257.—LEADING BLOCK.

LEADING BLOCK. TABLE OF DIMENSIONS.

Weight of Anchor	A	B	C	D	E	E₁	F	F₁	G	H	I	K	K₁
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
136 to 121	20	6¾	6½	¾	2¼	2	3	2¾	⅝	6¾	1	½	21
120 „ 106	20	6¾	6½	¾	2¼	2	2¾	2½	⅝	6¾	1	½	21
105 „ 91	18	6¼	6	⅞	2	1¾	2½	2¼	½	6¼	⅞	7/16	18¾
90 „ 76	18	6¼	6	[illegible]	2	1¾	2¼	2	½	6¼	⅞	7/16	18½
75 „ 61	16	5¾	5¾	13/16	1¾	1⅝	2⅛	1⅞	½	5¾	¾	⅜	16¾
60 „ 45	16	5½	5¼	11/16	1¾	1½	2	1¾	½	5½	¾	⅜	16½
44 „ 35	14	4¾	4¾	⅝	1½	1½	1¾	1½	7/16	4¾	⅝	5/16	14¾
34 „ 26	12	4½	4¼	9/16	1¼	1¼	1½	1½	7/16	4½	⅝	5/16	12½
25 „ 18	10	3¾	3¾	½	1⅛	1¼	1¼	1⅛	⅜	3¾	9/16	¼	10¾
17 „ 12	10	3¾	3¾	½	1⅛	1⅛	1⅛	1	⅜	3½	7/16	¼	10½
11 „ 7	9	3½	3¼	7/16	1	1	1	⅞	⅜	3¼	⅜	3/16	9¾

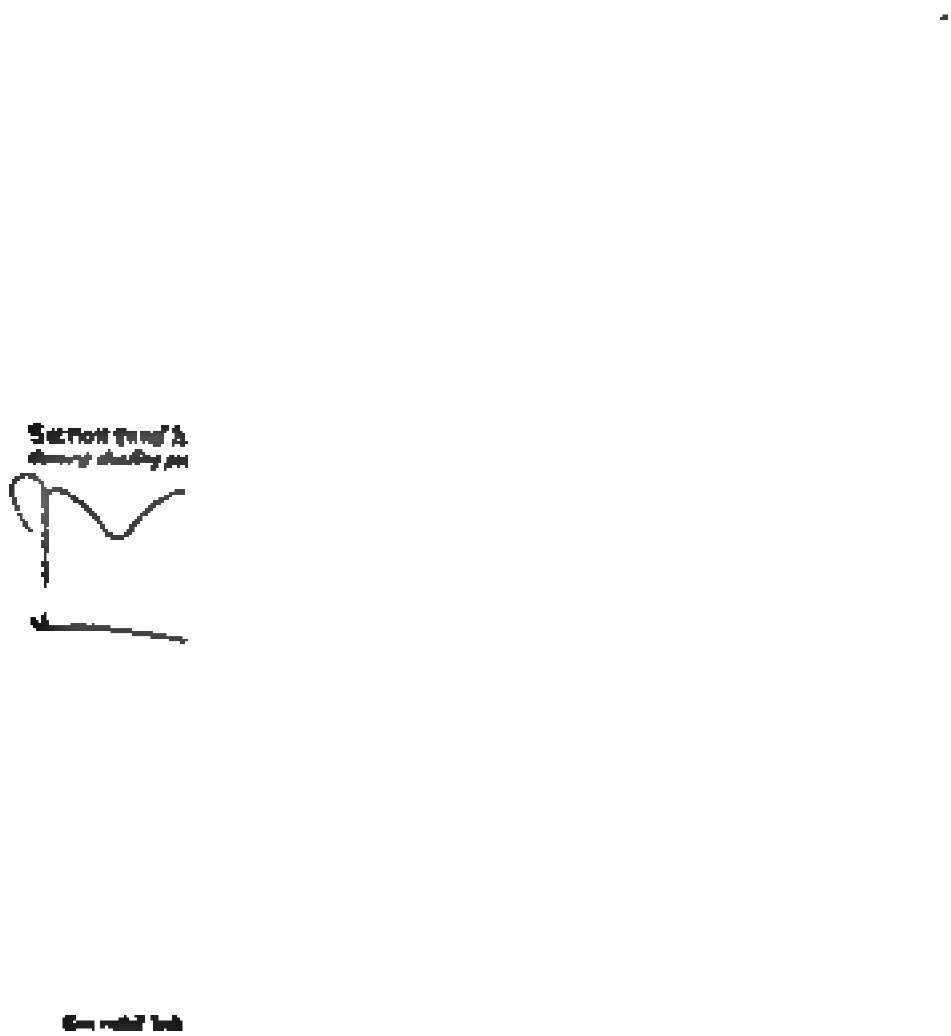
Leading Block. Table of Dimensions (*continued*).

Weight of Anchor	L	L₁	M	M₁	M₂	N	N₁	O	P	Q	R	R₁	S
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
135 to 121	2	6¾	1 5/16	1 5/16	6⅞	⅞	3¼	2	2	2¾	2⅞	3¼	3¼
120 „ 106	1⅞	6¼	1 3/16	1 3/16	6¼	⅞	3⅛	1¾	1¾	2⅝	2⅝	3⅛	3
105 „ 91	1¾	5¾	1 1/16	1 1/16	6⅛	¾	2⅞	1⅝	1⅝	2½	2⅜	3	2⅞
90 „ 76	1⅝	4⅞	15/16	1 1/16	5	11/16	2¾	1½	1½	2	2¼	2¾	2⅝
75 „ 61	1½	4½	⅞	1 1/16	4¾	⅝	2½	1⅜	1⅜	1⅞	2	2½	2½
60 „ 45	1⅜	4	13/16	1	4½	⅝	2⅜	1¼	1¼	1¾	1⅞	2⅜	2¼
44 „ 35	1¼	3¾	11/16	⅞	4	9/16	2	1⅛	1⅛	1⅝	1¾	2	1⅞
34 „ 26	1⅛	3½	⅝	13/16	3½	9/16	2	1	1	1½	1⅝	1¾	1¾
25 „ 18	1	2⅞	9/16	11/16	3	½	1⅞	⅞	⅞	1⅜	1½	1⅝	1⅝
17 „ 12	⅞	2⅝	½	⅝	2¾	½	1¾	¾	¾	1	1⅜	1½	1½
11 „ 7	¾	2	7/16	9/16	2½	7/16	1½	⅝	⅝	¾	1	1⅜	1¼

Weight of Anchor	T	U	U₁	V	V₁	W	X	X₁	Y₁		Z	Z₁	a
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.			Ins.	Ins.	Ins.
135 to 121	6½	3½	3⅜	5½	6½	3½	3½	8¼	1¼	⅞	3½	7½	2½
120 „ 106	6	3⅜	3¼	5	6	3⅜	2⅞	7⅞	1⅛	⅞	3⅜	6⅞	2⅜
105 „ 91	5¾	3¼	3⅛	4¾	5¾	3	2¾	7½	1⅛	¾	3	6½	2
90 „ 76	5½	3⅛	3	4½	5½	2⅞	2⅝	6⅞	1⅛	¾	2⅞	5⅞	2
75 „ 61	5	2⅞	2¾	4¼	5	2¾	2½	6	1⅛	11/16	2¾	5½	1⅞
60 „ 45	4¾	2¾	2⅝	3⅞	4⅝	2½	2⅜	5½	1	11/16	2⅝	4½	1¾
44 „ 35	4⅜	2⅝	2½	3⅝	4	2¼	1⅞	4⅞	⅞	⅝	2	4	1⅝
34 „ 26	3¾	2¼	2	3	3½	2	1¾	4¼	13/16	⅝	1⅞	3½	1⅝
25 „ 18	3⅜	1⅞	1⅞	2⅝	3¼	1⅞	1⅝	3⅞	11/16	9/16	1¾	3	1½
17 „ 12	2⅞	1¾	1¾	2½	2⅞	1¾	1½	3⅝	⅝	½	1½	2⅞	1⅜
11 „ 7	2⅝	1⅝	1½	1⅝	2⅝	1½	1⅜	3	½	7/16	1⅜	2½	1¼

Weight of Anchor	b	c	d	e	Proof Test	Size of Catting Pendant used, F.S.W. rope	Size of Ground Chain used	Size of Chafing-piece (f × g)
Cwts.	Ins.	Ins.	Ins.	Ins.	Tons	Ins.	Ins.	Ins.
135 to 121	1¼	⅞	1	1¼	68	4¾	1¼	1 × 2½
120 „ 106	1⅛	⅞	1	1⅛	60	4½	1⅛	1 × 2⅜
105 „ 91	1	⅞	⅞	1	53	4	1⅛	⅞ × 2¼
90 „ 76	1	¾	⅞	1	45	4	1⅛	⅞ × 2⅛
75 „ 61	⅞	¾	¾	⅞	37½	3¾	1	¾ × 1⅞
60 „ 45	¾	¾	¾	¾	30	3½	1	¾ × 1¾
44 „ 35	¾	⅝	⅝	¾	22	3	⅞	⅝ × 1⅝
34 „ 26	⅝	7/16	⅝	⅝	17	2¾	⅞	⅝ × 1½
25 „ 18	9/16	7/16	9/16	⅝	12½	2½	¾	½ × 1⅜
17 „ 12	9/16	⅜	7/16	½	8¾	2¼	¾	½ × 1⅛
11 „ 7	½	⅜	⅜	½	5¾	2	⅝	½ × 1

FIG. 36.—CATHEAD BLOCK.



CATHEAD BLOCK. TABLE OF DIMENSIONS.												
Weight of Anchor	A	B	C	D	E	E₁	F	F₁	G	H	I
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
135 to 121	20	6[illegible]	6[illegible]	[illegible]	2[illegible]	2	3	2[illegible]	[illegible]	6[illegible]	1
120 " 106	20	6[illegible]	6[illegible]	[illegible]	2[illegible]	2	2[illegible]	2[illegible]	[illegible]	6[illegible]	1
105 " 91	18	6[illegible]	6	[illegible]	2	1[illegible]	2[illegible]	2[illegible]	[illegible]	6[illegible]	[illegible]
90 " 76	18	6[illegible]	6	[illegible]	2	1[illegible]	2[illegible]	2	[illegible]	6[illegible]	[illegible]
75 " 61	16	6[illegible]	5[illegible]	[illegible]	1[illegible]	1[illegible]	2[illegible]	1[illegible]	[illegible]	5[illegible]	[illegible]
60 " 45	16	5[illegible]	5[illegible]	[illegible]	1[illegible]	1[illegible]	2	1[illegible]	[illegible]	5[illegible]	[illegible]
44 " 35	14	4[illegible]	4[illegible]	[illegible]	1[illegible]	1[illegible]	1[illegible]	1[illegible]	[illegible]	4[illegible]	[illegible]
34 " 26	12	4[illegible]	4[illegible]	[illegible]	1[illegible]	1[illegible]	1[illegible]	1[illegible]	[illegible]	4[illegible]	[illegible]
25 " 18	10	3[illegible]	3[illegible]	[illegible]	1[illegible]	1[illegible]	1[illegible]	1[illegible]	[illegible]	3[illegible]	[illegible]
17 " 12	10	3[illegible]	3[illegible]	[illegible]	1[illegible]	1[illegible]	1[illegible]	1	[illegible]	3[illegible]	[illegible]
11 " 7	9	3[illegible]	3[illegible]	[illegible]	1	1	1	[illegible]	[illegible]	3[illegible]	[illegible]

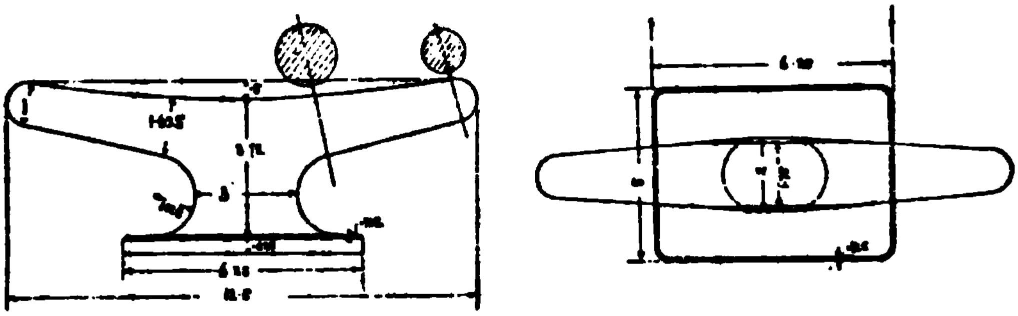
CATHEAD BLOCK. TABLE OF DIMENSIONS (*continued*).

Weight of Anchor	K	K_1	L	L_1	M	M_1	M_2	N	N_1	O	P
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
135 to 121	1/2	21	2	5 3/4	1 5/16	1 9/16	6 3/4	3/4	3 1/4	2	2
120 „ 106	1/2	21	1 7/8	5 1/2	1 3/16	1 7/16	6 1/4	5/8	3 1/4	1 3/4	1 3/4
105 „ 91	7/16	18 3/4	1 3/4	5 1/4	1 1/16	1 5/16	5 5/8	1/2	2 7/8	1 5/8	1 5/8
90 „ 76	7/16	18 3/4	1 5/8	4 7/8	15/16	1 3/16	5	7/16	2 7/8	1 1/2	1 1/2
75 „ 61	3/8	16 1/2	1 1/2	4 1/2	7/8	1 1/16	4 3/4	3/8	2 1/2	1 3/8	1 3/8
60 „ 45	3/8	16 1/2	1 3/8	4	13/16	1	4 1/2	3/8	2 1/2	1 1/4	1 1/4
44 „ 35	5/16	14 1/2	1 1/4	3 1/2	11/16	7/8	4	5/16	2	1 1/8	1 1/8
34 „ 26	5/16	12 3/8	1 1/8	3 1/8	5/8	13/16	3 1/2	5/16	2	1	1
25 „ 18	1/4	10 3/8	1	2 3/4	9/16	11/16	3	1/4	1 3/4	7/8	7/8
17 „ 12	1/4	10 3/8	7/8	2 3/8	1/2	5/8	2 3/4	1/4	1 3/4	3/4	3/4
11 „ 7	3/16	9 1/4	3/4	2	7/16	9/16	2 1/2	3/16	1 1/2	5/8	5/8

Weight of Anchor	Q	R	S	T	U	V	W	Z	*a*	*b*	*c*
Cwts.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins	Ins.	Ins.	Ins.	Ins.
135 to 121	2 3/4	2 3/4	3 1/8	3 1/8	3 1/4	3 1/4	10 1/2	1/2	2 1/2	1 1/4	3/4
120 „ 106	2 1/2	2 1/2	2 7/8	2 7/8	3 1/8	3 1/8	10	1/2	2 1/2	1 1/4	3/4
105 „ 91	2 1/4	2 1/4	2 5/8	2 5/8	3	3	9 1/2	3/8	2	1	5/8
90 „ 76	2	2	2 3/8	2 3/8	2 3/4	2 3/4	8 1/2	3/8	2	1	5/8
75 „ 61	1 7/8	1 7/8	2 1/4	2 1/4	2 1/2	2 1/2	7 1/2	3/8	1 3/4	7/8	1/2
60 „ 45	1 3/4	1 3/4	2 1/8	2 1/8	2 1/4	2 1/4	6 1/2	3/8	1 3/4	7/8	1/2
44 „ 35	1 1/2	1 1/2	1 3/4	1 3/4	2 1/8	2 1/8	5 3/4	3/8	1 1/2	3/4	1/2
34 „ 26	1 3/8	1 3/8	1 5/8	1 5/8	2	2	5	5/16	1 3/8	5/8	7/16
25 „ 18	1 1/8	1 1/8	1 3/8	1 3/8	1 3/4	1 3/4	4 1/4	5/16	1 1/4	9/16	7/16
17 „ 12	1	1	1 1/4	1 1/4	1 1/2	1 1/2	3 1/2	1/4	1 1/4	9/16	3/8
11 „ 7	7/8	7/8	1	1	1 1/4	1 1/4	2 3/4	1/4	1 1/8	1/2	3/8

Weight of Anchor	*d*	*e*	Proof Test	Size of Catting Pendant used, F.S.W. rope	Size of Ground Chain used	Size of Chafing piece ($f \times g$)
Cwts.	Ins.	Ins.	Tons	Ins.	Ins.	Ins.
135 to 121	1	1 1/4	68	4 1/2	1 1/4	1 × 2 1/2
120 „ 106	1	1 1/4	60	4 1/2	1 1/4	1 × 2 1/2
105 „ 91	7/8	1	55	4	1 1/8	7/8 × 2 1/8
90 „ 76	7/8	1	45	4	1 1/8	7/8 × 2 1/8
75 „ 61	3/4	7/8	37 1/2	3 1/2	1	3/4 × 1 3/4
60 „ 45	3/4	7/8	30	3 1/2	1	3/4 × 1 3/4
44 „ 35	5/8	3/4	22	3	7/8	5/8 × 1 3/8
34 „ 26	5/8	3/4	17	2 1/2	7/8	5/8 × 1 1/4
25 „ 18	9/16	5/8	12 1/2	2 1/4	3/4	1/2 × 1 1/8
17 „ 12	9/16	5/8	8 1/2	2 1/4	5/8	1/2 × 1 1/8
11 „ 7	1/2	1/2	5 1/2	2	1/2	3/8 × 1

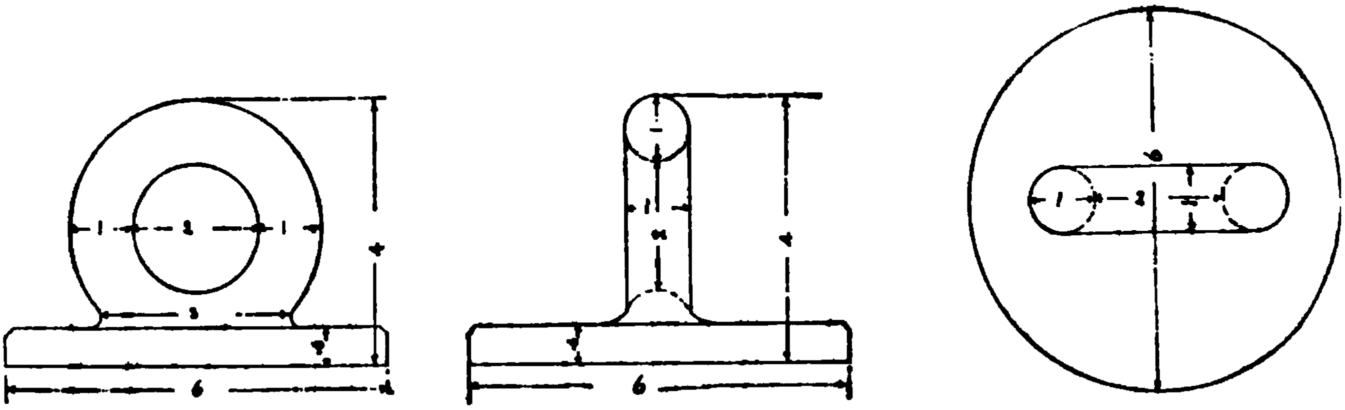
FIG. 259.—WROUGHT-IRON CLEAT.



Diameter of rope = $2\frac{1}{2}$ inches.

Note.—The dimensions given are multiples of the diameter at the tip.

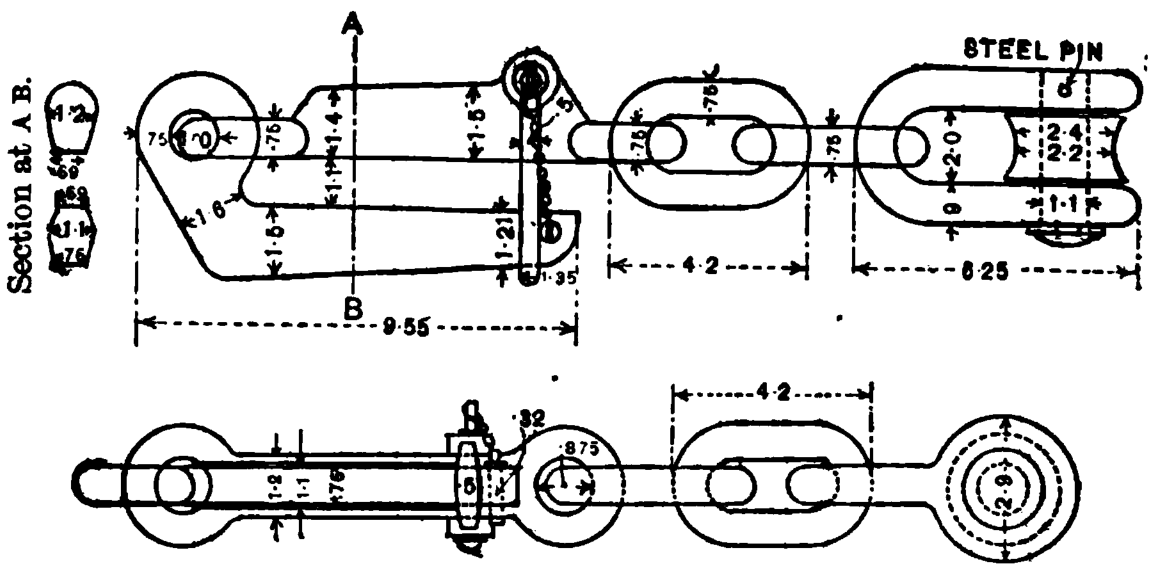
FIG. 260.—EYE-PLATE FOR GENERAL PURPOSES.



Note.—The dimensions given are multiples of the eye.

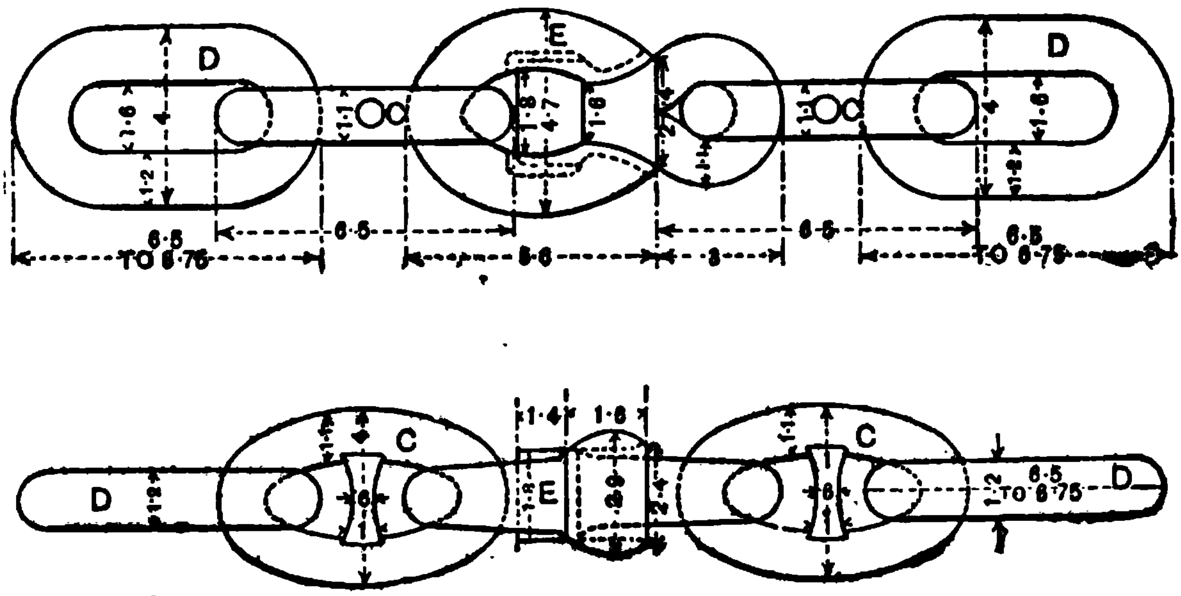
The proof strain in tons of eye-bolts or eye-plates is 10 times the square of the diameter in inches.

FIG. 261.—CLEAR HAWSE SLIP.



Note.—The dimensions given are multiples of the eye.

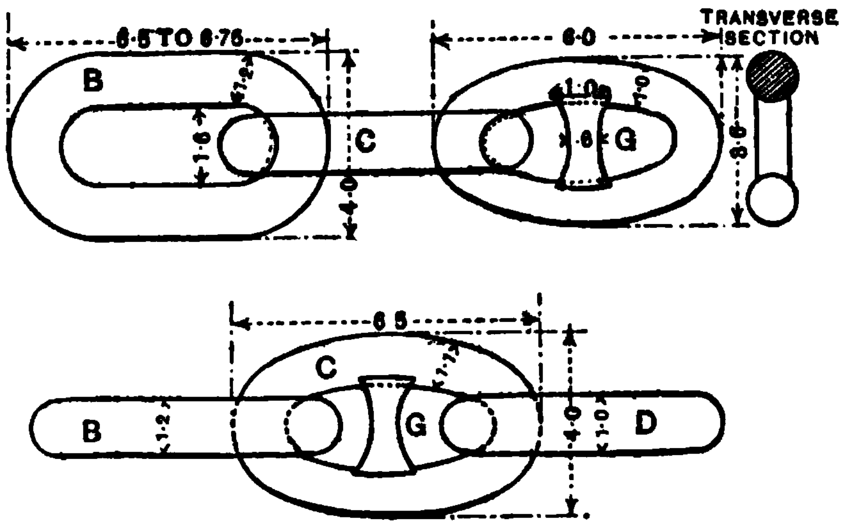
FIG. 262.—SWIVEL-PIECE.



C C, enlarged links (with stay-pins).
D D, end links.
E, swivel.

Note.—The dimensions given are multiples of the diameter of the cable.

FIG. 263.—END LINK, ENLARGED LINK (WITH STAY-PIN), AND COMMON LINK OF CHAIN CABLE.



B, end link (without stay-pin).
C, enlarged link (with stay-pin).
D, common link.
G, stay-pin.

Note.—The dimensions given are multiples of the diameter of the cable.

Size of Baths.

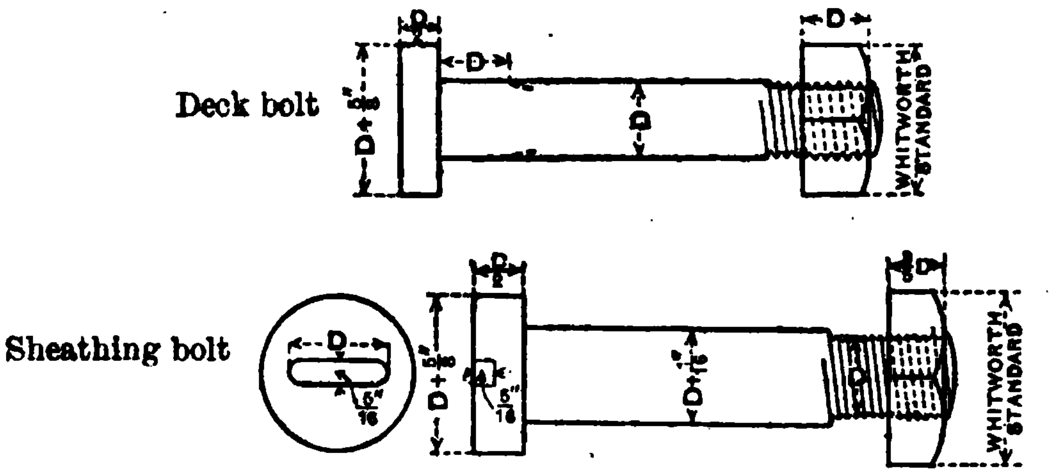
	Length ft.	Length in.	Breadth ft.	Breadth in.	Breadth ft.	Breadth in.	Depth ft.	Depth in.
At top . .	5	4	1	10	1	$4\frac{1}{2}$	1	$10\frac{1}{4}$
At bottom . .	4	$2\frac{1}{2}$	1	$4\frac{1}{2}$	1	$2\frac{1}{2}$		

Deck Bolts.

Screw-bolts of $\frac{3}{16}''$ diameter, with hexagonal or square heads and nuts, are to conform to Whitworth's standard gauges for nuts and bolts of the respective sizes, and are to be round under the heads. The diameter of square heads and nuts is to be reckoned across the sides, the same as for the hexagonal form. Bolts with round heads—deck bolts—are to have hexagonal nuts, the nuts to conform to Whitworth's standard gauges for the respective sizes; the diameter of the heads to be $\frac{5}{8}''$ more than that of the bolt, and the thickness of the heads to be half the diameter of the bolt. These bolts to be square under the head for a distance equal to the diameter of the bolt.

Bolt heads to be let into deck $\frac{1}{4}$ the thickness of deck screw-bolts, wrought iron, $\frac{7}{8}''$ to $1\frac{1}{4}''$, for fastening the wood sheathing of iron ships; diameter of bolt to be measured over screw part; plain part to be $\frac{1}{16}''$ larger, and round under the head. Heads to be round, of a diameter $\frac{5}{8}''$ greater than the diameter of bolt; thickness of head to be half the diameter of bolt. The head is to contain a slot equal in length to the diameter of the bolt, and of a breadth and depth of $\frac{5}{16}''$ for all diameters of bolts. Nuts to conform as to diameter to Whitworth's standard gauges for the respective sizes, but the thickness to be in all cases $\frac{4}{5}$ of the diameter of bolt.

Fig. 264.



The screwed part is to be truly concentric with the head and plain part, for screwing into metal through wood without enlarging the hole in the latter,

The screwing of all the above descriptions of bolts is to be Whitworth's standard thread.

SEASONING TIMBER.

Natural Seasoning.

THIS is performed by exposing the timber freely to the air in a dry place sheltered from the wind and sun, and so stacked as to admit of the air passing freely over all the surfaces of the pieces. Timber for carpenter's work will require about two years to season it properly; for joiner's work, about four years, or even longer.

Seasoning by a Vacuum.

The timber is placed in a chamber from which the air is exhausted, heat being at the same time employed so as to vaporise the exuded juices, the vapour being conveyed away by means of pipes surrounded by cold water.

Seasoning by Hot Air (Davidson).

The timber is placed in a chamber and exposed to a current of hot air impelled by a fan at the rate of about 100 feet per second, the air passages, fan, and chamber being so arranged that one-third of the volume of air in the chamber is blown through it per minute.

The temperature of the hot air varies for different kinds of timber as follows:—

Oak of any dimensions .	105° F.
Bay mahogany 1" boards .	280°–300°
Leaf woods in logs . .	90°–100°
Pine woods in thick pieces	120°

Water Seasoning.

This is done by immersing the timber in water—if shallow and salt it is better than fresh—and letting it remain there for periods averaging from 10 to 20 years, but it is sometimes only allowed to remain 14 days, when it is taken out and stood upright in some sheltered place where the air can get at it thoroughly, so as to render it quite dry. Sometimes it is thoroughly boiled or steamed for a day or two instead of being immersed in cold water for longer periods. All these processes tend rather to injure the strength of the wood, making it softer, although it tends to prevent cracking, warping, and shrinking.

Note.—Slowly seasoned timber is tougher and more elastic than when it is rapidly dried.

Seasoning by heat alone is very injurious to timber, as it produces a hard crust on the surface and prevents the moisture from evaporating.

For joiner's work and carpentry natural seasoning should have the preference.

PRESERVING TIMBER.

CREOSOTING. (*Bethell.*)

THE timber is first well dried, either by being freely exposed to the thorough circulation of the air or dried in an oven at a temperature varying from 90° to 100° Fahr., depending on the kind of timber.

One process is then to place the timber in a strong iron cylinder, and subject it to a vacuum of 6 to 12 lbs. per square inch for 30 or 40 minutes. The creosote is then allowed to flow in, and a pressure put upon it, varying from 100 to 150 lbs. per square inch, for about 1 to 2½ hours. The other process consists in simply immersing the timber in an open tank containing hot creosote, the temperature being kept up to about 120° to 150° Fahr., and left for some time to the natural process of absorption.

Note.—Ordinary fir timber absorbs from 8 to 10 lbs. of creosote per cubic foot of timber; red pine, from 15 to 16 lbs.; memel, from 10 to 12 lbs.; oak, from 4 to 5 lbs. This method of preserving timber is the most generally used; it is a sure preventive against the attack of the teredo and other marine worms.

IMPREGNATION WITH METALLIC SALTS.

Kyan's Process.

This consists in immersing the timber in a solution of bichloride of mercury diluted with about 100 to 150 parts of water, or about 1 to ⅝ of a lb. of the salt to 10 gallons of water. Twenty-four hours are usually allowed for each inch in thickness for boards, &c.

Margary's Process.

Margary employed sulphate of copper diluted with about 40 to 50 parts of water, applied with pressure varying from 15 to 30 lbs. per square inch for 6 or 8 hours.

Burnett's Process.

A solution of about 1 lb. of chloride of zinc to 4 or 5 gallons of water is injected and applied with a pressure varying from 100 to 120 lbs. per square inch for about 15 minutes. The timber is then taken out and allowed to dry for about 14 days. The timber should remain immersed for about 2 days for every inch in thickness.

Payne's Process.

Payne's process consists in impregnating the timber with a strong solution of sulphate of iron, and afterwards forcing in a solution of any of the carbonate alkalies.

TIMBER MEASURE.

In estimating quantities of timber duodecimals are usually employed—that is, the foot, inch, seconds, &c., are each divided into twelve parts instead of ten, as in common decimal fractions; so that by this means feet, inches, and seconds can be directly multiplied by feet, inches, and seconds. Thus:—

12 inches make 1 foot.	12 thirds make 1 second.
12 seconds make 1 inch.	12 fourths make 1 third.

And—

Feet multiplied by feet give feet.
Feet multiplied by inches give inches.
Feet multiplied by seconds give seconds.
Inches multiplied by inches give seconds.
Inches multiplied by seconds give thirds.
Seconds multiplied by seconds give fourths, &c.

To Multiply by Duodecimals.

Rule.—Place the several denominations of the multiplier directly under the corresponding denominations of the multiplicand.

Then multiply each denomination in the multiplicand by the number of feet in the multiplier, and place each product under its corresponding denomination in the multiplicand, always carrying one for every twelve.

In the same manner multiply by the number of inches, and set each product one place farther to the right hand.

Then multiply by the number of seconds, and set each product another place farther to the right hand.

Thus proceed with all the other denominations, and the sum of all the products will be the whole product required.

Example 1.

Multiply 3 ft. 6½ ins. by 2 ft. 5¼ ins.

	ft.	ins.	secs.		
	3	6	6		
	2	5	3		
	7	1	0		
	1	5	8	6	
			10	7	6
Ans.	8	7	7	1	6

Example 2.

Multiply 2 ft. 7 ins. 4. secs. 8 thirds by 1 ft. 2 ins. 3 secs. 3 thirds.

	ft.	ins.	secs.	thrds.			
	2	7	4	8			
	1	2	3	3			
	2	7	4	8			
		5	2	9	4		
			7	10	2	0	
				7	10	2	0
Ans.	3	1	3	11	4	2	0

To Find the Solid Contents of Round or Unsquared Timber.

Rule 1.—Multiply the square of the quarter-girt by the length, and the product will be the solid contents.

Rule 2.—Find the area in the following table which corresponds to the quarter-girt in inches, and multiply it by the length of the timber in feet; the product will be the solid contents in cubic feet and decimals of a cubic foot.

Examples.

What is the solid contents of a tree whose girt is 60 inches and whose length is 18 feet?

By Rule 1.

	ft.	ins.	secs.
4)60			
ins. 15 =	1	3	
	1	3	
	1	3	
		3	9
ft.	1	6	9

	ft.	ins.	secs.
	18	0	0
	1	6	9
	18	0	0
	9	0	0
	1	1	6
Ans.	28	1	6

By Rule 2.

4)60

15 ins.

Corresponding to 15 ins. in the table is 1·562 feet, and

sq. ft.
1·562
18
12496
1562
Ans. 28·112

Table of Constants for Measuring Timber.

Girt/4 Ins.	Area. Sq. Ft.	Girt/4 Ins.	Area. Sq. Ft.	Girt/4 Ins.	Area. Sq. Ft.	Girt/4 Ins.	Area. Sq. Ft.	Girt/4 Ins.	Area. Sq. Ft.
6	·250	9¾	·660	13½	1·266	17¼	2·066	24	4·000
6¼	·271	10	·694	13¾	1·313	17½	2·127	24½	4·168
6½	·293	10¼	·730	14	1·361	17¾	2·188	25	4·340
6¾	·316	10½	·766	14¼	1·410	18	2·250	25½	4·516
7	·340	10¾	·803	14½	1·460	18½	2·377	26	4·694
7¼	·365	11	·840	14¾	1·511	19	2·507	26½	4·877
7½	·391	11¼	·879	15	1·562	19½	2·641	27	5·063
7¾	·417	11½	·918	15¼	1·615	20	2·778	27½	5·252
8	·444	11¾	·959	15½	1·668	20½	2·918	28	5·444
8¼	·473	12	1·000	15¾	1·723	21	3·063	28½	5·641
8½	·502	12¼	1·042	16	1·778	21½	3·210	29	5·840
8¾	·532	12½	1·085	16¼	1·834	22	3·361	29½	6·043
9	·563	12¾	1·129	16½	1·891	22½	3·516	30	6·250
9¼	·594	13	1·174	16¾	1·948	23	3·674	31	6·674
9½	·626	13¼	1·219	17	2·007	23½	3·835	32	7·111

Timber Measures.

40 cubic feet of unhewn timber					= 1 load.
50	„	„	squared	„	
600 superficial feet of 1-inch planks or deals					
400	„	„	$1\frac{1}{2}$	„	„
300	„	„	2	„	„
240	„	„	$2\frac{1}{2}$	„	„
200	„	„	3	„	„
170	„	„	$3\frac{1}{2}$	„	„
150	„	„	4	„	„

100 „ „ make 1 square of boarding, flooring, &c.
120 deals = 1 hundred.
Battens are 7 ins. wide, deals 9 ins., and planks 11 ins.

Waste on Converting Timber.

African oak	= 100 per cent.	English oak	= 200 per cent.
American elm	= 15 „	„ „ plank	= 50 „
Dantzic fir plank	= 25 „	Greenheart	= 25 „
„ oak	= 50 „	Mahogany	= 30 „
„ „ plank	= 40 „	Quebec oak	= 10 „
English elm	= 200 „	Teak	= 15 „

Dantzic fir, when cut from planks . .	= 10 per cent.
Yellow pine, when cut for head and stern work	= 200 „
„ „ „ decks . . .	= 10 „

Plastering.

	1 In. Thick.	$\frac{3}{4}$ In. Thick.	$\frac{1}{2}$ In. Thick.
1 bushel of cement will cover	$1\frac{1}{7}$ sup. yd.,	$1\frac{1}{2}$ sup. yd.,	$2\frac{1}{4}$ sup. yds.
1 do. and 1 of sand „	$2\frac{1}{4}$ sup. yds.,	3 sup. yds.,	$4\frac{1}{2}$ „
1 „ 2 „ „	$3\frac{1}{3}$ „	$4\frac{1}{2}$ „	$6\frac{3}{4}$ „
1 „ 3 „ „	$4\frac{1}{2}$ „	6 „	9 „

1 cubic yd. of lime, 2 yds. of sand, and 3 bushels of hair will cover . . { 75 sup. yds. on brick. / 70 „ „ earth. / 60 „ „ laths.

Bricklaying.

	Size in Ins.	Weight in Lbs.
London stock bricks	$8\frac{3}{4} \times 4\frac{1}{4} \times 2\frac{3}{4}$	6·81
Red kiln . .	ditto.	7·00
Welsh fire . .	$9 \times 4\frac{1}{2} \times 2\frac{3}{4}$	7·84
Paving . . .	$9 \times 4\frac{1}{2} \times 1\frac{3}{4}$	5·00
Square tiles . .	$9\frac{3}{4} \times 9\frac{3}{4} \times 1$	5·70
„ . .	$6 \times 6 \times 1$	2·16

TABLE SHOWING THE NUMBER OF CUBIC FEET REQUIRED TO STOW ONE TON WEIGHT OF VARIOUS SUBSTANCES.

Substances	Cu. Ft. to a Ton	Substances	Cu. Ft. to a Ton
Ashes, pot and pearl	40	Indigo, in cases	66
Ballast, Thames	22	Linseed	56
Barley	47	Marl	28
Bread, in bulk	124	Molasses	60
Coal, Admiralty	48	Oats, in bulk	61
„ Newcastle	45	Rice, in bags	45
„ Welsh	40	Rum, in casks	60
Coffee, in bags	61	Saltpetre	36
Cotton, compressed	50	Sand, pit	22
Earth mould	33	„ river	21
Firewood	288	Sandstone	14
Flax	88	Shingle, clean	24
Flour, in barrels	50	Slate	13
Freestones	16	Sugar, in bags	39
Ginger	80	Tares, in bulk	48
Granite stone	14	Tea, in boxes	111
Gravel, coarse	23	Timber, hard	40
Hay, compressed	105	„ soft	50
„ uncompressed	140	Turmeric	66
Hemp	64	Silk, in bales	128
Hides, well packed	64	„ pieces, in cases	110
„ loosely packed	84	Wheat, in bulk	45

TABLE GIVING THE VARIOUS SUBSTANCES WHICH IN INDIA ARE RECKONED AT 50 CUBIC FEET TO THE TON MEASUREMENT.

Apparel	Elephants' teeth	Roping, in coils
Arrowroot, in cases	Ginger, in bags	Sago, in cases
Bee's wax	Gums, in cases	Sal ammoniac
Blackwood	Gunny bags	Sarsaparilla
Books	Hemp, in bales	Senna, in bales or bags
Borax, in cases	Hides and skins, in bales	Shellac, in cases
Camphor, in cases	Indigo, in cases	Silk piece goods
Cassia, all kinds	Mace, in cases	Skins
Cigars, in boxes	Mother-of-pearl, in cases	Soap, in bars
Cinnamon, in bales	Musk, in cases	Stick lac, in cases
Cloves, in chests	Nutmegs, in cases or casks	Tallow
Coffee, in cases or bags	Nux vomica, in bags	Tea, in chests
Coir fibre, in bales	Raw silk, in bales	Timber, hewn
Colocynth, in cases	Rhubarb, in cases	Tobacco, in bales
Cotton, in bales		Tortoise shells
Cowries, in bags		Wines, in casks
Cummin seed		Wool, in bales

QUANTITY OF PROVISIONS ALLOWED IN THE ROYAL NAVY PER 100 MEN FOR 90 DAYS.

Kind of Provision.	Quantity or Net Weight.	Gross Weight in lb. including tare.	Approximate Measurement in cubic feet.
Biscuit (ships without bakeries)	1,500 lb.	2,200	108
„ (ships with bakeries)	220 lb.	320	16
Beans or peas	550 lb.	620	20
Celery seed	3 lb.	3	—
Chocolate	300 lb.	345	6
Flour (ships with bakeries)	8,500 lb.	11,200	360
„ (ships without bakeries)	4,000 lb.	5,260	170
Jams and pickles	500 lb.	710	15
Lime-juice (home stations)	50 lb.	160	4
„ (foreign stations)	90 lb.	275	8
Milk (condensed)	800 lb.	1,240	26
Mustard	15 lb.	27	1
Oatmeal	100 lb.	113	5
Peas (split)	500 lb.	570	18
Pepper	15 lb.	27	1
Preserved meats	1,500 lb.	2,090	45
Rice	300 lb.	330	9
Rum	110 gal.	1,260	34
Salt (ships with bakeries)	250 lb.	320	10
„ (ships without bakeries)	200 lb.	255	8
Salt pork	1,050 lb.	1,900	48
Suet	80 lb.	116	3
Sugar	2,600 lb.	3,230	85
Tea	350 lb.	440	18
Vinegar	15 gal.	190	5
Total, average (with bakeries), ex rum	—	25,200	820

SCANTLINGS OF SAILING AND PULLING BOATS.

		36′ Pinnace.	34′ Cutter. Drop Keel.	30′ Gig. Drop Keel.	27′ Whaler. Drop Keel.	25′ Whaler. Drop Keel.	20′ Cutter. Gig.	16′ Dinghy.
Keel	Sided	4	3 fore end $4\frac{1}{2}$ centre plate	2 fore end 4 centre plate	$2\frac{1}{4}$ fore end 4 centre plate	2 fore end 4 centre plate	$2\frac{1}{4}$	$1\frac{3}{8}$
	Moulded	$7\frac{1}{2}$	5 mid length	$3\frac{1}{2}$ mid length	4 mid length	4 mid length	4	8
Stem	Sided	4	3	2	$2\frac{1}{4}$	2	$2\frac{1}{8}$	$1\frac{5}{8}$
	Moulded	$7\frac{1}{2}$	5	$3\frac{1}{2}$ at head 4 at forefoot	$3\frac{1}{2}$ at head $4\frac{1}{2}$ at forefoot	$3\frac{1}{2}$ at head $4\frac{5}{8}$ at forefoot	4	3 at head 4 at forefoot
Stern-post	Sided	4	—	—	$2\frac{3}{8}$	2	$2\frac{1}{8}$	$1\frac{5}{8}$
	Moulded	6 at head 15 at heel	—	—	$3\frac{3}{4}$ at head $4\frac{1}{2}$ at heel	$3\frac{1}{2}$ at head $4\frac{1}{2}$ at heel	3 at head 7 at heel	$2\frac{1}{2}$ at head 6 at heel
Hog		$8\frac{1}{2}\times2\frac{1}{2}$	7×1	$6\times\frac{3}{4}$	$6\times\frac{3}{4}$	$6\times\frac{3}{4}$	$4\frac{1}{2}\times\frac{3}{4}$	$8\frac{1}{4}\times\frac{3}{8}$
Timbers		$2\frac{1}{2}\times2\frac{1}{4}$ at heel $2\times1\frac{1}{2}$ at head	$1\frac{3}{4}\times1\frac{3}{8}$ at heel $1\frac{1}{2}\times1$ at head	$1\times\frac{3}{4}$	$\frac{7}{8}\times\frac{5}{8}$ at heel $\frac{3}{4}\times\frac{1}{2}$ at head	$\frac{7}{8}\times\frac{5}{8}$ at heel $\frac{3}{4}\times\frac{1}{2}$ at head	$1\frac{1}{8}\times\frac{5}{8}$ at heel $\frac{7}{8}\times\frac{5}{8}$ at head	$\frac{3}{4}\times\frac{1}{2}$ at heel $\frac{5}{8}\times\frac{7}{16}$ at head
Keelson		$8\frac{1}{2}\times2\frac{1}{2}$	$7\frac{1}{2}\times1\frac{1}{4}$	—	$6\times\frac{5}{8}$	$6\times\frac{5}{8}$	$5\frac{1}{2}\times\frac{3}{4}$	$5\frac{1}{2}\times\frac{1}{2}$
Shelf		$6\frac{1}{2}\times2$	—	—	—	—	—	—
Rising		—	$1\frac{1}{2}\times1\frac{1}{2}$	1×1	1×1	1×1	1×1	$\frac{3}{4}\times\frac{3}{4}$
Thwarts		$9\frac{1}{2}\times2\frac{1}{2}$	$7\times1\frac{1}{2}$	7×1	7×1	7×1	$7\times1\frac{1}{8}$	$7\times\frac{7}{8}$
Gunwales		$8\frac{3}{4}\times2\frac{1}{2}$	$8\frac{3}{8}\times1\frac{3}{8}$	$1\frac{1}{2}\times1\frac{1}{2}$	$1\frac{1}{2}\times1$	$1\frac{1}{2}\times1$	$1\frac{1}{2}\times1\frac{1}{8}$	$1\frac{1}{4}\times1\frac{1}{8}$
Transom		$2\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{8}$	—	—	$1\frac{1}{8}$	1
Rubbers		4×3	$3\frac{1}{4}\times2\frac{1}{4}$	$1\frac{1}{2}\times1$	$1\frac{1}{2}\times1\frac{1}{5}$	$1\frac{1}{4}\times1$	$1\frac{1}{2}\times1\frac{1}{8}$	$1\times\frac{7}{8}$
Plank	Carvel	$2-\frac{1}{2}$	—	$\frac{1}{4}$ inner $\frac{5}{16}$ outer	—	—	—	—
	Clinker	—	$\frac{1}{2}$	—	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{3}{8}$
	Material	Teak	Wych or Sand Elm	Honduras Mahogany	Wych or Sand Elm	Wych or Sand Elm	Wych or Sand Elm	Yellow Pine
Sail Area		555 sq. ft.	400 sq. ft.	247 sq. ft.	186 sq. ft.	180 sq. ft.	96 sq. ft.	70 sq. ft.

All dimensions (except sail area) in inches.

Lifting Weight of Boats.

Boat.	No. of men (life-saving capacity).	Length in feet.	Breadth (ex rubbers).		Depth (top of hog to top of main gunwale).		Lifting weight (ex slings).		
			ft.	in.	ft.	in.	tons.	cwt.	qrs
50′ Steel Pinnace . .	70	50	9	9	4	8½	15	0	0
45′ Steel Barge . . .	55	45	9	6	4	8¾	14	0	0
35′ Motor Boat . . .	46	35	7	7¼	4	0	4¾	0	0
30′ ,, ,, ...	40	30	7	1¼	3	10½	4	0	0
25′ ,, ,, ...	33	25	6	9½	3	4	2	7	0
20′ ,, ,, ...	20	20	6	1¾	2	9	1	10	0
42′ Launch (auxiliary motor)	130	42	11	2	4	3½	8	7	0
36′ Pinnace	85	36	9	9½	3	1½	5	0	0
34′ Cutter (drop keel) .	66	34	8	10½	3	1	2	3	0
30′ Gig ,, ,, .	26	30	5	9	2	4½		19	0
27′ Whaler ,, ,, .	27	27	6	0	2	2		18	2
25′ Whaler ,, ,, .	22	25	5	10½	2	2		16	3
16′ Dinghy	10	16	5	6	2	1¼		6	3
20′ Cutter Gig . . .	17	20	4	9	1	11¼		12	2

Colours for Working Drawings.

Material.	Representative Colour
Armour . .	neutral tint.
Brass . . .	gamboge or chrome yellow.
Brickwork .	crimson lake or carmine.
Cast iron . .	neutral tint or Payne's grey.
Clay or earth	burnt umber.
Coal . . .	diluted Indian ink.
Copper . .	carmine or lake mixed with burnt sienna
Glass . . .	green.
Lead . . .	Indian ink tinged with Prussian blue.
Oil	pink (tinged).
Steel . . .	pale blue tinged with lake or carmine.
Water . .	green.
Wood . . .	burnt sienna.
Wrought iron or mild steel	Prussian blue.

Note.—The usual method is to colour at least all the sectional parts; when both parts are coloured the sectional are coloured much darker than the other parts.

TIDES.

General Tide Table.

To London Times.		H.	M.	Rise. Spring. Feet.	Neap. Feet.
Aberdeen . . .	sub.	1	7	12	10
Ardrossan . . .	add	9	38	10	8
Ayr	„	9	43	8¾	7¼
Banff	sub.	1	39	10½	8
Belfast	add	8	36	9½	8
Calf of Man . . .	„	9	10	16¼	13
Campbeltown . . .	„	9	38	8½	6
Cantyre, Mull of . .	„	8	28	4	—
Cardiff	„	5	11	37½	29
Carlingford Bar . .	„	8	53	14	11
Deal	„	9	8	16	12½
Donegal	„	3	11	11½	8½
Downs	„	0	38	15	—
Dublin Harbour . .	„	9	2	13	10
Dumbarton . . .	sub.	1	47	9	—
Fleetwood . . .	add	9	5	26¼	19¾
Galloway, Mull of . .	„	9	8	15	12
Glasgow, Port . .	sub.	1	49	9	—
Gravesend	„	0	57	17½	14
Holyhead . . .	add	8	4	16	12½
Holy Island	„	0	23	15	11½
Kinsale	„	2	36	11½	9
Lamlash	„	9	42	10	7
Land's End	„	2	23	—	—
Larne, Quay	„	9	13	30	27¾
Leith, Albert Dock Sill .	„	0	32	28	24
Londonderry	„	5	54	7¾	5½
Maryport	„	9	42	21½	15½
Moville	„	5	36	7½	5½
Nore Light	„	10	24	15	12
Plymouth (Breakwater) .	„	8	55	16	11
Portland Bill	„	4	47	9	6
Portsmouth (Spithead) .	„	9	46	13	16
Queenstown	„	3	34	11	8½
Runcorn	„	9	42	16	8
Southampton	„	9	2	13	9
Sunderland	„	1	30	14	11
Troon	„	10	5	10	8
Tyne River Channel .	„	1	54	11	8
Whitehaven	„	9	28	25	19

The tide is on the average 49 minutes later each day, or 24½ minutes later each tide. The times of high water at London Bridge are approximately 1–45 for the nearest tide to new or full moon, and 6–50 for the nearest tide to first or last quarter. The times of intermediate tides may be obtained approximately by division.

Sizes and Tests of Weston's Differential Pulley Blocks and Chain.

Differential Pulley Blocks.

Description	Weight to be lifted in Tons	Tested to Weight in Tons
Upper pulley, with sprocket wheel *	4	6
Lower ,, ...	4	6
Upper ,, with sprocket wheel *	3	$4\frac{1}{2}$
Lower ,, ...	3	$4\frac{1}{2}$
Upper ,, with sprocket wheel *	2	3
Lower ,, ...	2	3
Upper ,, ...	1	$1\frac{1}{2}$
Lower ,, ...	1	$1\frac{1}{2}$
Upper ,, ...	$\frac{1}{2}$	$\frac{3}{4}$
Lower ,, ...	$\frac{1}{2}$	$\frac{3}{4}$
Upper ,, ...	$\frac{1}{4}$	$\frac{3}{8}$
Lower ,, ...	$\frac{1}{4}$	$\frac{3}{8}$

Chain for Ditto.

Diameter of Iron of Link	Length of Chain	Width of Link	Chain tested to	Block to Lift
Inches	Inches	Inches	Tons	Tons
$\frac{5}{8}$	$3\frac{1}{8}$	$1\frac{15}{16}$	$4\frac{5}{8}$	4
$\frac{9}{16}$	$2\frac{25}{32}$	$1\frac{3}{4}$	$3\frac{3}{4}$	3
$\frac{7}{16}$	$2\frac{1}{16}$	$1\frac{7}{16}$	$2\frac{1}{4}$	2
$\frac{5}{16}$	$1\frac{17}{32}$	1	$1\frac{1}{8}$	1
$\frac{1}{4}$	$1\frac{1}{4}$	$\frac{25}{32}$	$\frac{3}{4}$	$\frac{1}{2}$
$\frac{7}{32}$	$1\frac{3}{16}$	$\frac{23}{32}$	$\frac{23}{40}$	$\frac{1}{4}$

* All sprocket wheels are to work with $\frac{1}{4}$-inch chain.

SIZES AND TESTS OF ENGINEERS' TACKLE BLOCKS, WROUGHT IRON WITH GUNMETAL SHEAVES.

Description	Weight of Blocks Complete		Weight to be Lifted	Diam. of Sheave	Finished Weight of Sheave		Size of Rope	Proof Strain to be borne without Injury	Description	Weight of Blocks Complete		Weight to be Lifted	Diam. of Sheave	Finished Weight of Sheave		Size of Rope	Proof Strain to be borne without Injury
	Lbs.	Oz.	Tons	Inches	Lbs.	Oz.	Inches	Tons		Lbs.	Oz.	Tons	Inches	Lbs.	Oz.	Inches	Tons
Double	382	0	20	$14\frac{3}{4}$	47	13	$7\frac{1}{2}$	30	Treble	470	0	20	$14\frac{3}{4}$	48	11	$7\frac{1}{2}$	30
,,	177	0	11	$11\frac{1}{4}$	26	5	$4\frac{3}{4}$	18	,,	217	0	11	$11\frac{1}{4}$	26	5	$4\frac{3}{4}$	18
,,	79	0	8	$8\frac{3}{8}$	13	13	4	12	,,	98	8	8	$8\frac{3}{8}$	13	13	4	12
,,	63	0	6	$7\frac{5}{8}$	10	6	$3\frac{1}{2}$	9	,,	78	0	6	$7\frac{5}{8}$	10	5	$3\frac{1}{2}$	9
,,	39	8	4	$6\frac{1}{16}$	6	5	$3\frac{1}{4}$	6	,,	48	0	4	$6\frac{1}{16}$	6	2	$3\frac{1}{4}$	6
,,	21	12	$2\frac{1}{2}$	$4\frac{7}{8}$	3	$2\frac{1}{2}$	3	$3\frac{3}{4}$	,,	26	8	$2\frac{1}{2}$	$4\frac{7}{8}$	3	6	3	$3\frac{3}{4}$
,,	14	12	$1\frac{1}{2}$	$4\frac{1}{4}$	2	6	$2\frac{1}{2}$	$2\frac{1}{4}$	,,	18	8	$1\frac{1}{2}$	$4\frac{1}{4}$	2	4	$2\frac{1}{2}$	$2\frac{1}{4}$
,,	10	0	1	$3\frac{3}{4}$	1	$8\frac{1}{2}$	2	$1\frac{1}{2}$	,,	12	8	1	$3\frac{3}{4}$	1	9	2	$1\frac{1}{2}$

GALVANISED BLOCKS FOR DERRICKS WITH GUNMETAL SHEAVES.

Description	Size of Block	Weight of Block Complete		Gunmetal Sheave				Diameter of Pin	Proof Strain of Block
				Thickness	Diameter	Finished Weight			
	Ins.	Lbs.	Ozs.	Ins.	Ins.	Lbs.	Ozs.	Ins.	Tons
… t iron shell	5	5	10	1	$2\frac{5}{8}$		$13\frac{1}{2}$	$\frac{3}{4}$	1
… ockle with … fittings	$7\frac{1}{2}$	18	6	$1\frac{1}{16}$	$3\frac{3}{8}$	1	6	$\frac{7}{8}$	$2\frac{1}{4}$
	$7\frac{1}{2}$	21	7	$1\frac{1}{16}$	$3\frac{7}{8}$	1	6	$\frac{7}{8}$	$2\frac{1}{2}$
… t iron shell and wrought iron fittings	6	6	1	$1\frac{1}{16}$	$3\frac{5}{16}$	1	2	$\frac{5}{8}$	$1\frac{1}{2}$

WROUGHT IRON BLOCKS FOR TORPEDO NET DEFENCE, WITH CAST STEEL SHEAVES.

Description	Size of Block	Weight of Block Complete	Cast Steel Sheaves		Diameter of Pin	Swivel Eye			Proof Strain
			Thickness	Diameter		Size in Clear	Diameter of Iron	Diameter of Hole	
	Ins.	Lbs.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Tons
Blocks.—Wrought iron, with swivel eye and cast steel sheave to reeve $3\frac{1}{2}$ inch steel wire rope	$23\frac{1}{2}$	118	$2\frac{3}{16}$	$18\frac{1}{2}$	$2\frac{1}{4}$	$4\frac{3}{4}\times3\frac{1}{4}$	$1\frac{5}{8}$	2	16
Sheaves.—Cast steel spar for above blocks	—	—	$2\frac{5}{16}$	$18\frac{1}{2}$	—	—	—	—	16
Blocks.—Wrought iron, with swivel eye and cast steel sheave to reeve $2\frac{1}{2}$ inch steel wire rope	$17\frac{1}{2}$	$61\frac{1}{2}$	$1\frac{9}{16}$	13	$1\frac{1}{2}$	$4\frac{3}{4}\times2\frac{1}{2}$	$4\frac{1}{2}$	$1\frac{1}{2}$	12
Sheaves.—Cast steel spar for above blocks	—		$1\frac{9}{16}$	13	—	—	—	—	12

Note.—The blocks in the above table to be of best wrought iron, except the guide plates, which are to be of open-hearth steel. The sheaves to be steel castings of the usual Admiralty quality,* bushed with phosphor bronze, the groove for taking the rope to be machined.

tensile stress per square inch, 26 tons; 2nd, minimum elongation rectangular section as near to this area as possible, 40°; 4th, each

Single Wrought Iron Lift Blocks with Padlock Shackles and Gunmetal Sheaves

Size of Block	Weight of Block complete	Flexible Steel Wire Rope: Size to Reeve	Flexible Steel Wire Rope: Breaking Strain	Flexible Steel Wire Rope: Diameter when served	Gunmetal Sheave: Thickness	Gunmetal Sheave: Diameter	Gunmetal Sheave: Finished Weight	Diameter of Pin	Shackle: Diameter of Iron	Shackle: Size in clear	Shackle: Bolts: Diameter of Oval	Shackle: Bolts: Diameter of Round	Shackle: Lug	Proof Strain of Block
ins.	lbs. oz.	ins.	tons	ins.	ins.	ins.	lbs. oz.	ins.	ins.	ins.	ins.	ins.	ins.	tons
		$1\frac{1}{2}$	4	$\frac{5}{8}$										
$6\frac{3}{4}$	7 8				$\frac{7}{8}$	5	2 7	$\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{8} \times 1\frac{1}{2}$	$\frac{3}{4} \times \frac{3}{8}$	$\frac{9}{16}$	$\frac{9}{32} \times \frac{3}{4}$	3
		$1\frac{3}{4}$	$5\frac{1}{2}$	$\frac{3}{4}$										
		2	7	$\frac{7}{8}$										
9	18 8				$1\frac{1}{8}$	7	5 8	1	$\frac{7}{8}$	$1\frac{1}{2} \times 2$	$1 \times \frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{8} \times 1$	5
		$2\frac{1}{4}$	9	1										
		$2\frac{1}{2}$	$11\frac{3}{4}$	$1\frac{1}{8}$										
12	39 8				$1\frac{3}{8}$	9	12 6	$1\frac{1}{4}$	$1\frac{1}{8}$	$2 \times 2\frac{1}{2}$	$1\frac{1}{4} \times \frac{5}{8}$	1	$\frac{1}{2} \times 1\frac{1}{4}$	9
		3	17	$1\frac{1}{4}$										
		$3\frac{1}{2}$	24	$1\frac{3}{8}$										
15	79 8				$1\frac{3}{4}$	$11\frac{1}{2}$	23 8	$1\frac{5}{8}$	$1\frac{7}{16}$	$2\frac{1}{2} \times 3\frac{1}{4}$	$1\frac{5}{8} \times \frac{13}{16}$	$1\frac{1}{4}$	$\frac{5}{8} \times 1\frac{5}{8}$	15
		4	31	$1\frac{5}{8}$										
		$4\frac{1}{2}$	39	$1\frac{3}{4}$										
18	131 0				$2\frac{1}{4}$	14	35 4	2	$1\frac{3}{4}$	$3\frac{1}{2} \times 4\frac{1}{2}$	2×1	$1\frac{1}{2}$	$\frac{3}{4} \times 2$	29
		5	59	2										

Wrought Iron Snatch Blocks with Gunmetal Sheaves

Weight of Block complete	Weight to be Lifted	Size of Block: Across the Sheave	Size of Block: Length of Shell in direction of Strap	Gunmetal Sheaves: Thickness	Gunmetal Sheaves: Diameter	Gunmetal Sheaves: Finished Weight	Diameter of Pin	Proof Strain of Blocks
lbs. oz.	tons	ins.	ins.	ins.	ins.	lbs. oz.	ins.	tons
55 8	6	$8\frac{1}{2}$	16	$1\frac{3}{4}$	$7\frac{3}{4}$	12 9	$1\frac{3}{8}$	9
37 8	4	$7\frac{1}{2}$	$14\frac{1}{4}$	$1\frac{1}{2}$	$7\frac{1}{8}$	7 12	$1\frac{1}{8}$	6
25 0	$2\frac{1}{2}$	$6\frac{3}{4}$	13	$1\frac{1}{4}$	$6\frac{1}{2}$	6 1	1	5

Miscellaneous Wrought Iron Blocks with Gunmetal Sheaves

Description	Size of Block	Weight of Block complete	Gunmetal Sheave: Thickness	Gunmetal Sheave: Diameter	Gunmetal Sheave: Finished Weight	Diameter of Pin	Oval Hook: Size of Iron	Oval Hook: Length	Oval Hook: Opening	Tests: Working Load	Tests: Test Load
	Ins.	Lbs. Oz.	Ins.	Ins.	Lbs. Oz.	Ins.	Ins	Ins.	Ins.	Tons	Tons
Blocks with swivel hook, single	5	3 9	$\frac{13}{16}$	$2\frac{11}{16}$	— $12\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{16} \times \frac{13}{16}$	$3\frac{3}{8}$	1	$\frac{1}{2}$	$\frac{3}{4}$
Ditto	7	7 0	$1\frac{3}{8}$	$3\frac{1}{2}$	2 2	$\frac{3}{4}$	$1\frac{3}{16} \times 1$	$3\frac{3}{4}$	$1\frac{3}{16}$	$\frac{5}{16}$	$1\frac{1}{4}$
Blocks with swivel hook, double, with cross bar at head becket and belaying pin . . .	6	7 $12\frac{1}{2}$	$\frac{13}{16}$	$3\frac{1}{2}$	— 14	$\frac{5}{8}$	$1\frac{3}{16} \times 1$	$3\frac{3}{4}$	$1\frac{3}{16}$	1	$1\frac{1}{2}$
Blocks with swivel hook, treble, with cross bar at head without becket	6	9 3	$\frac{13}{16}$	$3\frac{1}{2}$	— 13	$\frac{5}{8}$	$1\frac{3}{16} \times 1$	$3\frac{3}{4}$	$1\frac{3}{16}$	1	$1\frac{1}{2}$
Blocks, single, for training tackles, with becket and thimbles	7	8 $7\frac{1}{2}$	$1\frac{1}{8}$	$3\frac{13}{16}$	1 13	$\frac{7}{8}$	$1\frac{3}{8} \times 1\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{9}{16}$	2	3
Blocks, single, for training tackles, without becket	7	8 0	$1\frac{1}{8}$	$3\frac{13}{16}$	1 13	$\frac{7}{8}$	$1\frac{3}{8} \times 1\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{9}{16}$	2	3

Table of Weight and Strength of Government Hawser Laid Cordage

Size of Yarn	Size of Rope in Ins.	Threads in ropes	Approximate Weight of Tarred per coil of 113 Fathoms			Breaking Strain		Approximate Weight of White per coil of 113 Fathoms			Breaking Strain	
			cwt.	qrs.	lbs.	tons	cwt.	cwt.	qrs.	lbs.	tons	cwt.
40 Thread Yarn Hemp. Tarred-Riga White-Italian	½	6	—	—	12½	—	3	—	—	10½	—	4½
	¾	12	—	—	25	—	6	—	—	21	—	9
	1	15	—	1	3¼	—	8	—	—	26½	—	12
	1¼	21	—	1	14	—	10	—	1	7	—	15
	1½	33	—	2	11	—	15	—	2	—	1	1
	1¾	42	—	3	1	1	—	—	2	15	1	8
	2	54	—	3	25	1	7	—	3	7	1	17
	2¼	66	1	—	21	1	14	—	—	—	—	—
	2½	84	1	2	1	2	—	1	1	1	2	18
	2¾	102	1	3	9	2	10	—	—	—	—	—
	3	120	2	—	17	3	—	1	3	5	4	4
30 Thread Yarn Hemp. Tarred-Riga White-Italian	3¼	106	2	2	1	3	10	—	—	—	—	—
	3½	123	2	3	21	3	18	2	1	22	5	12
	4	159	3	3	5	5	—	3	—	18	7	5
	4½	201	4	2	5	6	9	4	—	—	9	5
	5	249	5	3	21	7	18	4	3	22	11	10
	6	360	8	2	9	11	10	7	—	17	16	10
25 Thread Yarn Hemp. Tarred-Petersburg White-Italian	6½	351	10	—	4	12	16	—	—	—	—	—
	7	408	11	2	18	14	16	9	2	25	20	—
	7½	468	—	—	—	—	—	11	—	17	23	—
	8	534	15	1	1	19	8	12	2	25	26	—
	9	675	19	1	5	24	—	16	—	9	33	—
	12	1,200	—	—	—	—	—	28	2	9	58	10
	16	—	—	—	—	—	—	—	—	—	110	—

Table of Weight and Strength of Government Coir Rope (3 Strand)

Size of Rope in Ins.	Weight of coil of 113 Fathoms			Breaking Strain		Size of Rope in Ins.	Weight of coil of 113 Fathoms			Breaking Strain	
	cwt.	qrs.	lbs.	tons	cwt.		cwt.	qrs.	lbs.	tons	cwt.
2½	—	2	11	—	9½	6	3	1	21	2	17
3	—	3	12	—	14	7	4	2	19	3	16
3½	1	—	19	—	18½	8	6	0	11	4	17
4	1	2	2	1	5½	9	7	2	24	6	8
5	2	1	14	2	—	—	—	—	—	—	—

Table of Weight and Strength of Government Manilla Hawser

Manilla Hawser, 3 *Strands*. *In Coils of* 122 *Fathoms each.*

Size of Yarn	Size of Rope in Ins.	Threads in Ropes	Approximate Weight of White			Breaking Strain		Approximate Weight of Tarred			Breaking Strain	
			Cwt.	Qrs.	Lbs.	Tons	Cwt.	Cwt.	Qrs.	Lbs.	Tons	Cwt.
40 Thread	1	15	—	—	27	—	13	—	1	8	—	11½
	1½	33	—	2	0	1	3	—	2	8	1	1
	2	54	—	3	7	2	0	—	3	20	1	16
	2½	84	1	1	1	3	0	1	1	21	2	18
	3	120	1	3	5	4	12	2	0	6	4	4
30 Thread	3½	123	2	1	22	6	3	2	3	6	5	12
	4	159	3	0	18	7	19	3	2	12	7	5
	4½	201	4	0	0	9	13	4	2	8	9	5
	5	249	4	3	22	12	13	5	2	18	11	10
	5½	303	6	0	2	15	5	6	3	14	13	15
	6	360	7	0	17	18	0	8	0	19	16	10

Manilla Hawser, 4 *Strands*. *In Coils of* 113 *Fathoms each.*

Size of Yarn	Size of Rope in Inches	Threads in Strand	Threads in Heart	Total Threads in Rope	Approximate Weight of White			Breaking Strain		Approximate Weight of Tarred			Breaking Strain	
					Cwt.	Qrs.	Lbs.	Tons	Cwt.	Cwt.	Qrs.	Lbs.	Tons	Cwt.
	1	3	2	14	—	—	24	—	10	—	—	27½	—	9
	1½	7	4	32	—	1	25	1	1	—	2	4½	—	18
	2	12	5	53	—	3	4	1	16	—	3	16½	1	13
	2½	20	7	87	1	1	4	2	14	1	1	24½	2	9
	3	28	10	122	1	3	6	4	3	2	0	7	3	15
	3½	29	9	125	2	1	25	5	11	2	3	8	5	0
	4	37	12	160	3	0	17	7	3	3	2	11½	6	9
	4½	47	15	203	4	0	0	8	14	4	2	8	7	17
	5	58	21	253	4	3	25	11	8	5	2	20½	9	18
	5½	71	24	308	6	0	7	13	15	6	3	20	12	8
	6	84	30	366	7	0	21	16	4	8	0	24	14	12

Table of Weight and Strength of Government Cordage (Various).

Size of Rope	No. of Threads in Rope	Description of Rope	Length of Coil	Weight per Coil			Breaking Strain	
Ins.			Fathoms	Cwt.	Qrs.	Lbs.	Tons	Cwt.
2	36	Lasso	102	—	2	24	1	10
1¼	27	Signal halyard . .	122	—	1	7	1	3
1½	9	White packing—Russian hemp	280	1	0	0	—	—
1¾	12	White packing—Russian hemp	200	1	0	0	—	—
2	15	White packing—Russian hemp	155	1	0	0	—	—
—	—	White spun yard (flax), 5 thread	280	—	2	0	—	—
—	—	Hambro' Line (Russian hemp), 3 strand 12 thread	20	—	—	3	—	—
—	—	White deep-sea line, cable laid, 3 strand 9 thread	42	—	—	9½	—	—
—	—	Large, 3 strand 6 thread	196	—	1	0	—	—
—	—	Small, 3 thread . .	280	—	1	0	—	—

Table of Weight and Strength of Government Bolt Rope Cordage.

Size of Yarn	Size of Rope in Inches	Threads in Rope	Approximate weight of Tarred per Coil of 122 Fathoms			Breaking Strain		Approximate weight of White per Coil of 122 Fathoms			Breaking Strain	
			Cwt.	Qrs.	Lbs.	Tons	Cwt.	Cwt.	Qrs.	Lbs.	Tons	Cwt.
40 thread Italian hemp	½	6	—	—	12½	—	3¾	—	—	—	—	—
	¾	12	—	—	25	—	7½	—	—	—	—	—
	1	15	—	1	3½	—	9⅓	—	—	—	—	—
	1¼	21	—	1	14	—	12½	—	1	7	—	15
	1½	33	—	2	11	—	19	—	2	0	1	2
	1¾	42	—	3	1	1	3	—	2	15	1	10
	2	54	—	3	25	1	10	—	3	7	1	17
	2¼	66	1	0	21	1	18	—	3	27	2	7
	2½	84	1	2	1	2	10	1	1	1	2	18
	2¾	102	1	3	9	3	0	—	—	—	—	—
	3	120	2	0	17	3	10	1	3	5	4	8
30 thread Italian hemp	3¼	105	2	2	1	4	0	—	—	—	—	—
	3½	123	2	3	21	4	12	2	1	22	5	11
	4	159	3	3	5	6	0	3	0	18	7	5
	4½	201	4	3	5	7	12	—	—	—	—	—
	5	249	5	3	21	9	0	4	3	22	11	7
	7	489	11	2	17	18	10	—	—	—	—	—
	8	639	15	0	25	24	0	—	—	—	—	—

TABLE SHOWING BREAKING STRENGTHS OF FLEXIBLE STEEL WIRE ROPES FOR CRANES, SLINGS, SHEERLEGS, LAUNCHING CHECKS, ETC.

If exposed to the weather these should be galvanized.

R. S. NEWALL & SON, LIMITED, LIVERPOOL AND GLASGOW.

Circ.	Weight per Fathom.	Made 6 Strands, each containing					
		19 wires.	27 wires.	37 wires.	48 wires.	61 wires.	91 wires
in.	lb.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1	·96	4 21	[illegible]·89	3 63	—	—	—
1¼	1·50	5·88	[illegible]·82	5·79	—	—	—
1½	2·17	8·91	8·13	8·40	—	—	—
1¾	2·92	11·28	11·[illegible]	10·82	—	—	—
2	3·84	15 51	14·62	14 41	13·62	—	—
2¼	4·84	19·95	19·24	18·54	18·18	—	—
2½	6·04	24·[illegible]	22 96	23·11	22 00	—	—
2¾	7·30	29·27	28·78	28·53	[illegible]·12	—	—
3	8·64	34·[illegible]	[illegible]	32·20	32·23	30 [illegible]	29·24
3¼	10·10	[illegible]·22	39·[illegible]	38·31	37·21	35·86	33·38
3½	11·70	47·[illegible]	46·23	44·84	[illegible]	41·74	[illegible] 90
3¾	13·6	55·[illegible]	52·36	51·97	50 30	48·08	45·00
4	15·36	61·89	58·94	57·67	56·58	[illegible] 68	[illegible]·15
4½	19·50	78·56	74 86	74 00	69·[illegible]	67·00	64·22
5	24·00	97 51	93 08	92 44	87·76	83·52	79·61
5½	29·20	—	115 43	112·90	[illegible] 49	101·[illegible]	93·75
6	34·60	—	134 72	129·62	128·32	121·75	116·[illegible]
6½	40·70	—	—	153·66	149·09	143·56	133·[illegible]
7	47·04	—	—	179·34	170 58	167·60	151·25
7½	54 00	—	—	208·12	201 67	192·27	180 00
8	61·44	—	—	230 29	226·53	219·46	200·79
8½	69·36	—	—	262 90	252 90	247·92	233·[illegible]
9	77·76	—	—	295 51	280·90	268·79	256·85

TABLE SHOWING THE MINIMUM DIAMETER OF DRUMS AND SHEA IN INCHES. (MESSRS. NEWALL.)

Galvanized Flexible Steel Wire Ropes
(R. S. Newall & Son, Ltd.).
For Towlines, Hawsers, Warps.
To Lloyd's and Board of Trade Requirements.
6 Strands, 12 Wires per Strand.

Circ.	Diam.	Weight per Fathom.	Breaking Strain.	Diam. of Drum.
in.	in.	lb.	Tons.	in.
1	·318	·67	2	3
1⅛	·358	·85	2½	3½
1¼	·398	1·10	3	4
1⅜	·437	1·25	3¾	5
1½	·477	1·50	4½	6
1⅝	·517	1·77	5	7
1¾	·557	2·05	5½	7½
1⅞	·596	2·36	6⅜	8
2	·636	2·70	7	8½
2⅛	·676	3·09	8	9
2¼	·716	3·42	9½	10
2½	·795	4·15	12½	12
2¾	·875	5·00	15½	14
3	·954	6·00	18	16
3¼	1·03	7·00	22	19
3½	1·11	8·00	26	22
3¾	1·19	9·50	29	25
4	1·27	10·50	33	30
4¼	1·35	12·18	35	33
4½	1·43	13·40	39	36
4¾	1·51	15·00	47	40

Special Flexible Galvanized Improved Patent Steel Wire Rope (R. S. Newall & Son, Ltd.).

For Hawsers, Cargo Falls, Running Rigging, etc.
Made 6 Strands of 24 Wires each.

To Lloyd's and Board of Trade Requirements.

Size. Circ.	Size. Diam.	Weight per Fathom.	B.S.	Diam. of Drum.
in.	in.	lb.	Tons.	in.
1	·318	·90	3·0	2
1⅛	·358	1·15	3·7	2½
1¼	·397	1·40	4·5	3
1⅜	·437	1·70	5·4	4
1½	·477	1·95	6·3	5
1⅝	·517	2·35	7·8	5½
1¾	·557	2·71	8·9	6
1⅞	·596	3·20	10·1	7
2	·636	3·67	11·7	7½
2⅛	·676	4·00	12·7	8
2¼	·716	4·50	14·8	9
2⅜	·756	5·10	16·4	10
2½	·795	5·75	18·2	11
2⅝	·835	6·20	19·7	12
2¾	·875	6·75	22·0	13
3	·955	8·00	26·2	14
3¼	1·034	9·00	30·7	16
3½	1·114	10·90	35·5	18
3¾	1·193	12·50	41·0	20
4	1·273	14·00	45·5	22
4¼	1·352	16·20	52·5	25
4½	1·432	18·00	59·0	28
4¾	1·512	20·00	65·5	30
5	1·591	22·25	73·0	33
5¼	1·671	24·12	78·5	35
5½	1·750	26·70	88·0	38
6	1·909	32·00	105·0	46

Special Flexible Steel Wire Rope.

When an owner prefers to substitute Special Flexible Steel Wire Ropes for wire rope of ordinary make, the sizes of the rope may be reduced in accordance with following table:—

Circ. 24/6	Circ. if made 12/6
in.	in.
1¾	2
2	2¼
2¼	2⅓
2½	2¾ & 3
2¾	3¼
3	3½
3¼	3¾
3½	4 & 4¼
3¾	4½
4	4⅝
4¼	4¾
4½	5 & 5¼
4¾	5⅜
5	5½
5½	6
6	7
6¼	7

Admiralty Requirements for Steel Wire Rope.

A. For Standing Rigging and Funnel Guys.			B. Flexible for Hawsers and Running Rigging.			C. Extra Special Flexible.			D. Extra Special Flexible (tinned for boat hoists).		
Wires in a Strand.	Weight per Fathom.	Breaking Load.	Wires in a Strand.	Weight per Fathom.	Breaking Load.	Wires in a Strand.	Weight per Fathom.	Breaking Load.	Wires in a Strand.	Weight per Fathom.	Breaking Load.
No.	lb.	Tons.	No.	lb.	Tons.	No.	lb.	Tons.	No.	lb.	Tons.
—	—	—	30	53	170	—	—	—	—	—	—
—	—	—	30	35	110	—	—	—	—	—	—
—	—	—	30	31	96½	—	—	—	91	35·6	124
—	—	—	—	—	—	—	—	—	61	32·6	118
—	—	—	24	26	81½	—	—	—	61	29·7	108
—	—	—	—	—	—	—	—	—	61	26·9	99
—	—	—	24	21¾	68	37	23·5	90	61	24·3	90
—	—	—	—	—	—	—	—	—	61	21·8	81
19	19½	57	12	14	43½	37	19	73	61	20·2	73
—	—	—	—	—	—	—	—	—	61	17·8	65
19	15½	45	12	10¾	33¼	37	15·3	58	61	15·7	58
7	11¾	35	12	8¼	25¼	37	11·5	45	61	11·9	45
7	8⅞	26	12	6	18¾	37	8·6	33	—	—	—
—	—	—	—	—	—	37	7·2	27½	—	—	—
7	5¾	17¾	12	4¼	13	37	5·8	22¼	—	—	—
—	—	—	—	—	—	37	4·6	18¼	—	—	—
7	3⅞	11¼	12	2¾	8½	37	3·8	14·7	—	—	—
7	2⅞	8¼	12	2	6¼	37	2·9	11¼	—	—	—
7	2	6¼	12	1½	4½	37	2·1	8¼	—	—	—
—	—	—	—	—	—	37	1·7	7	—	—	—
—	—	—	12	1	3¼	37	1·4	5¼	—	—	—
—	—	—	—	—	—	24	1·05	4·3	—	—	—
—	—	—	12	¾	2¼	24	·875	3·6	—	—	—
—	—	—	—	—	—	24	·675	2¾	—	—	—
—	—	—	—	—	—	19	·5	2·05	—	—	—
—	—	—	—	—	—	19	·35	1·4	—	—	—
—	—	—	—	—	—	19	·22	·9	—	—	—
—	—	—	—	—	—	19	·12	·5	—	—	—

Qualities A, B, C, to be galvanized by the hot process. ll to be made of the best quality steel. The wire to stand he following ductility tests :—

Test A.—To have the number of turns taken in itself indicated or each gauge of wire in the table below; distance between grips to be 8″ for sizes above ·036″, 4″ for sizes below ·026″, and 6″ for intermediate sizes.

Diam. in in.	·128	·122	·116	·110	·104	·098	·092	·086	·080	·076	·072
No. of turns	16	17	18	19	20	21	23	24	26	27	29
Diam. in in.	·068	·064	·060	·056	·052	·048	·044	·040	·038	·036	·034
No. of turns	30	32	34	37	40	43	47	52	55	43	46
Diam. in in.	·032	·030	·028	·026	·024	·022	·020	·018	·0148	·0116	·0092 and less
No. of turns	49	52	56	60	44	48	52	58	71	90	100

Test B.—To have eight turns taken round its own part and back again. The tensile tests on the ropes on a length of not less than six circumferences. The wires and strands to be laid in opposite directions.

The number of wires in a strand to be as follows:—

Quality A: 19 for 4″ and 4½″, 7 for other sizes; quality B: 30 for 6″ and over, 24 for 5″ and 5½″, 12 for other sizes; quality C: 37 for 1¼″ and over, 24 for ⅞″ to 1⅛″ 19 for other sizes; quality D: 91 for 6″, 61 for other sizes.

Useful Dimensions.

Suez Canal.—Minimum depth 30′; breadth 120′ on floor, 148′ at water level.

Manchester Ship Canal.—Minimum clear height of bridges above mean water level 74′ 6″; allow 2′ or 3′ for flood; size of locks 600′ × 65′.

Newcastle High-level Bridge.—Clear height above water at H.W.O.S.T. 83′ 1″. Add about 14′ at low water springs.

BULLIVANTS' STEEL WIRE ROPES (GALVANIZED).

Flexible Steel Wire Rope, 6 Strands, each 12 Wires				Extra Flexible Steel Wire Rope, 6 Strands, each 24 Wires		Special Extra Flexible Steel Wire Rope			
						6 Strands, each 37 Wires		Bullivants' Special Make	
Circumference	Weight per Fathom (Approx.)	Guaranteed Breaking Strain	Diameter of Barrel or Sheave round which it may be at a slow speed worked	Weight per Fathom (Approx.)	Guaranteed Breaking Strain	Weight per Fathom (Approx.)	Guaranteed Breaking Strain	Guaranteed Breaking Strain	Circumference
In.	Lbs.	Tons	In.	Lbs.	Tons	Lbs.	Tons	Tons	In.
1	·63	1·75	6	·88	2·95	1·0	—	—	1
1¼	1·06	2·5	7½	1·55	4·45	1·56	—	—	1¼
1½	1·44	4·0	9	1·88	6·7	2·00	7·25	—	1½
1¾	2 00	5·5	10½	2·68	8·75	2·88	10·0	—	1¾
2	2·44	7·0	12	3·78	11·85	4·0	13·0	—	2
2¼	3·37	9·0	13½	4·75	14·6	5·2	15·75	—	2¼
2½	4·19	12·0	15	5·31	18·55	6·3	19·75	—	2½
2¾	5·25	15·0	16½	6·12	21·95	6·81	24·0	—	2¾
3	6·25	18·0	18	8·0	25·7	8·81	29·0	—	3
3¼	7·06	22·0	19½	9·37	30·8	10·38	33·5	—	3¼
3½	8·25	26·0	21	10·75	35·2	11·9	38·5	—	3½
3¾	9·87	29 0	22½	12·19	41·1	13·5	44·5	—	3¾
4	11·25	33·0	24	13·62	46·3	15·3	51·0	—	4
4¼	12·35	36·0	25½	15·69	52·9	17·12	58·0	—	4¼
4½	13·44	39·0	27	17·75	58·6	19·0	63·5	—	4½
4¾	—	—	—	19·88	66·4	21·69	71·25	—	4¾
5	—	—	—	22·5	74·2	24·38	79·25	—	5
5¼	—	—	—	23·25	82·88	27·69	87·75	—	5¼
5½	—	—	—	24·5	91·55	31·0	96·75	—	5½
5¾	—	—	—	—	—	33·75	103·75	—	5¾
6	—	—	—	—	—	36·5	113·75	—	6
6½	—	—	—	—	—	42·5	132·0	—	6½
7	—	—	—	—	—	48·5	154·0	—	7
7½	—	—	—	—	—	55·0	178·5	—	7½
8	—	—	—	—	—	63·0	198·0	202	8
9	—	—	—	—	—	79·0	250·0	257	9
10	—	—	—	—	—	98·0	305·0	318	10
11	—	—	—	—	—	120·0	—	381	11
12	—	—	—	—	—	142·0	—	455	12

Note.—In these flexible rope tables the wire is calculated as taking a reaking strain of 90 tons to the square inch; ropes made of wire which is alculated above that will take a proportionately higher strain.

In crane ropes (black) the weights are the same, but the breaking loads f extra flexible and special ropes are about 11 per cent higher.

BULLIVANT'S PLOUGH STEEL WIRE STRANDED CORDS, TINNED, FOR BRACING, CONTROLS, ETC., FOR AIRCRAFT.

FLEXIBLE.			EXTRA FLEXIBLE.		
Approx. Circum. in Inches.	Approx. Breaking Load in Lb.	Approx. Weight in Lb. per 1000 ft.	Approx. Circum. in Inches.	Approx. Breaking Load in Lb.	Approx. Weight in Lb. per 1000 ft.
$\frac{3}{16}$	500	8	$\frac{19}{64}$	850	13
$\frac{1}{4}$	650	10	$\frac{5}{16}$	1200	18
$\frac{9}{32}$	1120	14	$\frac{11}{32}$	1500	20
$\frac{5}{16}$	1500	17	$\frac{13}{32}$	2000	27
$\frac{11}{32}$	1680	20	$\frac{7}{16}$	2450	32
$\frac{23}{64}$	1750	23	$\frac{1}{2}$	2900	38
$\frac{25}{64}$	2300	30	$\frac{9}{16}$	3400	50
$\frac{27}{64}$	2450	33	$\frac{19}{32}$	4200	56
$\frac{7}{16}$	2600	36	$\frac{5}{8}$	5000	64
$\frac{33}{64}$	3600	47	$\frac{11}{16}$	5500	80
$\frac{37}{64}$	4500	55	$\frac{23}{32}$	6250	90
$\frac{21}{32}$	6300	74	$\frac{3}{4}$	7250	100
—	—	—	$\frac{13}{16}$	8500	117
—	—	—	$\frac{27}{32}$	9600	124
—	—	—	1	11000	151

Note.—All these cords have 7 strands; the flexible cords have 7 wires per strand, and the extra flexible 19, except the $\frac{19}{64}''$ and $\frac{5}{16}''$ which have 12, and the $\frac{11}{32}''$ which has 14. The extra flexible is preferred in England, but the flexible is usually used on the Continent on account of its superior test, and its smaller liability to fray, kink, or corrode; the cost of flexible is also less by about 25 per cent.

The elongation at the breaking load lies between 1 per cent and 3 per cent; at any ordinary working load it is negligible.

General Notes on Wire Rope (Bullivant & Co.).

The diameter of pulleys and sheaves given on p. 580 is the minimum for slow speeds; with extra flexible and special extra flexible ropes the diameter can be somewhat reduced, but the best working results are always obtained with the diameter as large as possible.

Pulley groves should be so constructed that one-third of the rope's diameter is fully supported. The depth of groove should be 1½ times the diameter of the rope.

When reeving sufficient turn should be put in the rope to make the strands and wires "snug and tight". It is very detrimental to a wire rope to allow it to chafe or ride on its own part. All shocks shorten the life of a rope; the strain should be put on as gradually as possible.

Running ropes should preferably be ungalvanized. All ropes should be well and frequently lubricated; the lubricant should not contain acid or alkali, and the grease should be well worked into the interstices of the strands. Stock ropes should be kept in a dry place.

For ordinary purposes a factor of safety of six is sufficient; but in shafts and other high speed workings 30 is frequently adopted.

Crane ropes made of wires whose strength is up to 135 tons per square inch (instead of 100 tons as usual) can be obtained; but larger sheaves and barrels should be used. A moderately tempered wire gives a better working result than a highly tempered one.

Description of Hemp Cables.

Hemp is laid up *right-handed* into yarns.
Yarns are laid up *left-handed* into strands.
Three strands laid up *right-handed* make a hawser.
Three hawsers laid up *left-handed* make a cable.
Shroud-laid rope has a *core* surrounded by four strands.

BULLIVANT'S STANDARD CRAB-WINCH.

Lift from barrel in tons	½	1	2	2½	3	4	5
Circumference of rope in inches	1¼	1¾	2¼	2½	2¾	3¼	3½
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Extreme axial width between tips of handles	4 11¾	5 8½	6 10½	7 2¼	7 6¾	8 3¼	8 6½
Extreme height	2 10½	2 10½	3 5	4 0	4 3	4 6	4 10
Length between centres of bolt-holes in base	1 6	1 10¼	2 1½	2 4¼	2 6¾	2 11½	3 1½
Width between centre of bolt-holes	2 1¼	2 5¾	3 1¼	3 1⅜	3 5½	3 6½	3 11½
Extreme width of base	2 3½	2 8½	3 4½	3 5	3 9	3 11	4 3
Extreme length of base (in direction of rope)	2 0	2 4½	2 8	3 0	3 3	3 8	3 11
Height of axis of handles	2 4⅛	2 3¼	2 9½	3 3½	3 3½	3 3½	3 6
Diameter of barrel	0 6	0 8	0 10	0 10	1 0	1 1	1 3
Approximate weight in cwt.	2·9	4·8	7·8	10·0	12·5	17·0	19·0

LLOYD'S SIZES AND SCANTLINGS FOR YARDS AND TOPMASTS

YARDS

Length Cleated	Centre			1st Quarter			2nd Quarter			3rd Quarter		
	Diameter	Thickness		Diameter	Thickness		Diameter	Thickness		Diameter	Thickness	
		Iron	Steel		Iron	Steel		Iron	Steel		Iron	Steel
Feet	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
32	8	$\frac{3}{16}$	$\frac{3}{16}$	$7\frac{7}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$7\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	6	$\frac{3}{16}$	$\frac{3}{16}$
36	9	$\frac{3}{16}$	$\frac{3}{16}$	$8\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$8\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$6\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$
40	10	$\frac{3}{16}$	$\frac{3}{16}$	$9\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	9	$\frac{3}{16}$	$\frac{3}{16}$	$7\frac{1}{2}$	$\frac{3}{16}$	$\frac{3}{16}$
44	11	$\frac{3}{16}$	$\frac{3}{16}$	$10\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	10	$\frac{3}{16}$	$\frac{3}{16}$	$8\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$
48	12	$\frac{4}{16}$	$\frac{5}{20}$	$11\frac{3}{4}$	$\frac{4}{16}$	$\frac{5}{20}$	$10\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	9	$\frac{3}{16}$	$\frac{3}{16}$
52	13	$\frac{4}{16}$	$\frac{5}{20}$	$12\frac{5}{8}$	$\frac{4}{16}$	$\frac{5}{20}$	$11\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$9\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$
56	14	$\frac{4}{16}$	$\frac{5}{20}$	$13\frac{5}{8}$	$\frac{4}{16}$	$\frac{5}{20}$	$12\frac{5}{8}$	$\frac{4}{16}$	$\frac{5}{20}$	$10\frac{1}{2}$	$\frac{3}{16}$	$\frac{3}{16}$
60	15	$\frac{4}{16}$	$\frac{5}{20}$	$14\frac{5}{8}$	$\frac{4}{16}$	$\frac{5}{20}$	$13\frac{1}{8}$	$\frac{4}{16}$	$\frac{5}{20}$	$11\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$
64	16	$\frac{5}{16}$	$\frac{6}{20}$	$15\frac{5}{8}$	$\frac{5}{16}$	$\frac{6}{20}$	$14\frac{3}{8}$	$\frac{5}{16}$	$\frac{6}{20}$	12	$\frac{4}{16}$	$\frac{5}{20}$
68	17	$\frac{5}{16}$	$\frac{6}{20}$	$16\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$15\frac{1}{4}$	$\frac{5}{16}$	$\frac{6}{20}$	$12\frac{3}{4}$	$\frac{4}{16}$	$\frac{5}{20}$
72	18	$\frac{5}{16}$	$\frac{6}{20}$	$17\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$16\frac{1}{4}$	$\frac{5}{16}$	$\frac{6}{20}$	$13\frac{1}{2}$	$\frac{4}{16}$	$\frac{5}{20}$
76	19	$\frac{6}{16}$	$\frac{7}{20}$	$18\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$17\frac{1}{8}$	$\frac{5}{16}$	$\frac{6}{20}$	$14\frac{1}{4}$	$\frac{4}{16}$	$\frac{5}{20}$
80	20	$\frac{6}{16}$	$\frac{7}{20}$	$19\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	18	$\frac{5}{16}$	$\frac{6}{20}$	15	$\frac{4}{16}$	$\frac{5}{20}$
84	21	$\frac{7}{16}$	$\frac{8}{20}$	$20\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	19	$\frac{5}{16}$	$\frac{6}{20}$	$15\frac{3}{4}$	$\frac{5}{16}$	$\frac{6}{20}$
88	22	$\frac{7}{16}$	$\frac{8}{20}$	$21\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$19\frac{3}{4}$	$\frac{5}{16}$	$\frac{6}{20}$	$16\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$
92	23	$\frac{7}{16}$	$\frac{8}{20}$	$22\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$20\frac{3}{4}$	$\frac{6}{16}$	$\frac{7}{20}$	$17\frac{1}{4}$	$\frac{5}{16}$	$\frac{6}{20}$
96	24	$\frac{7}{16}$	$\frac{8}{20}$	$23\frac{3}{8}$	$\frac{6}{16}$	$\frac{7}{20}$	$21\frac{5}{8}$	$\frac{6}{16}$	$\frac{7}{20}$	18	$\frac{5}{16}$	$\frac{6}{20}$

TOPMASTS.—The plating should be of the thickness given in the table. The seams of topmasts may be single riveted; the butts should be treble riveted, and their straps $\frac{1}{16}$ of an inch thicker in iron topmasts, and $\frac{1}{20}$ thicker in steel than the plates they connect. There should be doubling plates in the way of the lower mast cap. Topmasts should be efficiently strengthened in the way of the fid holes and in the way of sheave holes where such are cut, by the doubling plates, iron hoops, or by other approved methods.

LOWER YARDS.—The plating should be of the thickness given in the table. The seams of yards may be single riveted; their

OF SAILING VESSELS AND FULL-RIGGED STEAM VESSELS.

YARDS			TOPMASTS									
ENDS AT CLEATS			LENGTH	HEEL			Lower Part of Head			HEAD		
Diameter	Thickness			Diameter	Thickness		Diameter	Thickness		Diameter	Thickness	
	Iron	Steel			Iron	Steel		Iron	Steel		Iron	Steel
Ins.	Ins.	Ins.	Feet	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
4	2/16	2/16	32	12	4/16	5/20	10½	4/16	5/20	9	3/16	3/16
4½	2/16	2/16	34	12½	4/16	5/20	11	4/16	5/20	9½	3/16	3/16
5	2/16	2/16	36	13	4/16	5/20	11½	4/16	5/20	10	3/16	3/16
5½	2/16	2/16	38	14	4/16	5/20	12½	4/16	5/20	10½	3/16	3/16
6	2/16	2/16	40	14½	4/16	5/20	13	4/16	5/20	11	3/16	3/16
6½	2/16	2/16	42	15	5/16	6/20	13½	4/16	5/20	11½	4/16	5/20
7	2/16	2/16	44	16	5/16	6/20	14	4/16	5/20	12	4/16	5/20
7½	2/16	2/16	46	16½	5/16	6/20	14½	4/16	5/20	12½	4/16	5/20
8	3/16	3/16	48	17	6/16	7/20	15	5/16	6/20	13	5/16	6/20
8½	3/16	3/16	50	18	6/16	7/20	16	5/16	6/20	13½	5/16	6/20
9	3/16	3/16	52	18½	6/16	7/20	16½	5/16	6/20	14	5/16	6/20
9½	3/16	3/16	54	19	6/16	7/20	17	5/16	6/20	14½	5/16	6/20
10	3/16	3/16	56	20	6/16	7/20	18	5/16	6/20	15	5/16	6/20
10½	4/16	5/20	58	20½	6/16	7/20	18½	5/16	6/20	15½	5/16	6/20
11	4/16	5/20	60	21	6/16	7/20	19	5/16	6/20	16	5/16	6/20
11½	4/16	5/20	62	22	6/16	7/20	20	5/16	6/20	16½	5/16	6/20
12	4/16	5/20	64	23	6/16	7/20	21	5/16	6/20	17	6/16	6/20

butts should be treble riveted, and connected by being overlapped, or by efficient butt straps. The plates should be doubled at the centre, and the doubling plates should extend beyond the truss hoops.

Where iron or steel masts and yards are to be constructed otherwise than in accordance with the tables, plans and particulars of the same must be submitted for the approval of the Committee.

Where steamers are intended to be fitted with topmasts for auxiliary purposes, they might be one-eighth less in diameter than prescribed by table.

LLOYD'S TABLE OF SIZES FOR THE STEEL

Register Tonnage under Deck	Tons 3,000 and under 3,500		Tons 2,600 and under 3,000		Tons 2,300 and under 2,600		Tons 2,000 and under 2,300	
Plating Number	24,200 and under 27,200		21,900 and under 24,200		20,000 and under 21,900		18,400 and under 20,000	
	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.
Fore & Main Shrouds . .	6 and 2 cap	5½	6 and 2 cap	5¼	6 and cap	5	6 and cap	4⅞
" " Chain plates .		2¾		2⅝		2½		2⅜
" " Dead-eyes . .		—		—		—		—
" " Lanyards (hemp)		—		—		—		—
" " Rigging Screws (Diameter at bottom of thread)		2¼		2⅛		2		1⅞
" " Rigging Screws (Diameter of Pins)		2		1⅞		1¾		1⅝
" " Topmst. bckstys.	3	5½	3	5¼	3	5	3	4⅞
" " Top-gllt. bckstys.	2	4¼	2	4⅛	2	3⅞	2	3¾
" " Lower stays .	2	5½	2	5¼	2	5	2	4⅞
" " Topmast stays .	2	5½	2	5¼	2	5	2	4⅞
" " Top-gllt. stays .		4¼		4⅛		3⅞		3¾
Mizen Shrouds	5 and cap	4½	5 and cap	4⅜	5 and cap	4¼	5 and cap	4⅛
" Topmast backstays .	3	4½	3	4⅜	3	4¼	3	4⅛
" Top-gallant backstays	2	3¼	2	3⅛	2	3	2	2⅞
" Lower stays . . .	2	4½	2	4⅜	2	4¼	2	4⅛
" Topmast stays . .	2	4½	2	4⅜	2	4¼	2	4⅛
" Top-gallant stays .		3¼		3⅛		3		2⅞
Bobstay Bar		4⅛		4⅛		4		3⅞
" Pin		3⅛		3⅛		3		2⅞
" Chain		$2\frac{1}{16}$		$2\frac{1}{16}$		2		$1\frac{15}{16}$
Bowsprit Shrouds (Chain) .	2	1⅛	2	1⅛	2	$1\frac{1}{16}$	2	$1\frac{1}{16}$

1. The above requirements are intended to apply to vessels in which the imensions of the masts and yards are such as would not be deemed unusual for essels of the respective tonnages; where these dimensions are extreme, or in ;her exceptional cases where deviations from the above sizes are required, gging plans showing the sizes and arrangements of the several parts should be ıbmitted for the approval of the Committee.

2. Where four masts are adopted instead of three, the tonnage of the vessel ıay be reduced one-fifth, and where five masts are adopted, one-fourth, in obtaining ıe sizes of rigging, &c., from the above table.

Wire Standing Rigging, etc., of Sailing Ships.

Tons 1,800 and under 2,000		Tons 1,600 and under 1,800		Tons 1,400 and under 1,600		Tons 1,200 and under 1,400		Tons 1,000 and under 1,200	
17,000 and under 18,400		15,600 and under 17,000		14,200 and under 15,600		12,800 and under 14,200		11,400 and under 12,800	
No.	Size Ins.	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.
6 and cap	4¾	6 and cap	4½	6 and cap	4¼	6 and cap	4⅛	6 and cap	4
	2¼		2⅛		2		1⅞		1⅞
	12×7		11½×6½		11×6		10½×6		10×6
	6		5¾		5½		5¼		5
	1⅞		1¾		1¾		1⅝		1⅝
	1⅜		1½		1½		1⅜		1⅜
3	4¾	3	4½	3	4¼	3	4⅛	3	4
2	3½	2	3¼	2	3	2	2¾	2	2⅝
2	4¾	2	4½	2	4¼	2	4⅛	2	4
2	4¾	2	4½	2	4¼	2	4⅛	2	4
	3½		3¼		3		2¾		2⅝
5 and cap	4	5 and cap	3¾	5 and cap	3½	5 and cap	3¼	5	3
3	4	3	3¾	3	3½	3	3¼	3	3
2	2¾	2	2½	2	2¼	2	2⅛	2	2
2	4	2	3¾	2	3½	2	3¼	2	3
2	4	2	3¾	2	3½	2	3¼		3
	2¾		2½		2¼		2⅛		2
	3¾		3⅝		3½		3¼		3
	2¾		2⅝		2½		2¼		2⅛
	$1\frac{14}{16}$		$1\frac{13}{16}$		$1\frac{12}{16}$		$1\frac{10}{16}$		$1\frac{9}{16}$
2	1	2	1	2	⅞	2	⅞	2	$\frac{13}{16}$

3. Where pole masts are adopted in vessels requiring one cap shroud only, an additional cap shroud is to be fitted, when the number of lower shrouds may be correspondingly reduced.

4. Where double top-gallant yards are to be adopted, a topmast cap backstay should be fitted in addition.

LLOYD'S TABLE OF SIZES FOR THE STEEL

Register Tonnage under Deck	Tons 800 and under 1,000		Tons 700 and under 800		Tons 600 and under 700		Tons 500 and under 600	
Plating Number	10,000 and under 11,400		9,000 and under 10,000		8,000 and under 9,000		7,100 and under 8,000	
	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.	No.	Size Ins.
Fore & Main Shrouds . .	5 and cap	3¾	5 and cap	3½	5 and cap	3¼	5	3
„ „ Chain plates .		1¾		1¾		1⅝		1⅜
„ „ Dead-eyes . .		9½ × 5½		9 × 5½		8½ × 5		8 × 5
„ „ Lanyards (hemp)		4¾		4½		4¼		4
„ „ Rigging Screws (Diameter at bottom of thread)		1½		1½		1⅜		1¼
„ „ Rigging Screws (Diameter of Pins)		1⅜		1⅜		1¼		1⅛
„ „ Topmst. bckstys.	2	3¾	2	3½	2	3¼	2	3
„ „ Top-gllt. bckstys.	2	2½		2⅜		2¼		2⅛
„ „ Lower stays .	2	3¾	2	3½	2	3¼	2	3
„ „ Topmast stays .	2	3¾	2	3½		3¼		3
„ „ Top-gllt. stays .		2½		2⅜		2¼		2⅛
Mizen Shrouds	5	2⅞	5	2¾	4	2⅝	4	2½
„ Topmast backstays .	2	2⅞	2	2¾	2	2⅝		2½
„ Top-gallant backstays.		1⅞		1¾		1⅝		1½
„ Lower stays . . .		2⅞		2¾		2⅝		2½
„ Topmast stays . .		2⅞		2¾		2⅝		2½
„ Top-gallant stays. .		1⅞		1¾		1⅝		1½
Bobstay Bar		2½		2¼		2		2
„ Pin		1⅞		1⅝		1½		1½
„ Chain . . .		1 9/16		1 5/16		1 3/16		1 1/16
Bowsprit Shrouds (Chain) .	2	13/16		12/16		11/16		10/16

5. The steel wire ropes are to be guaranteed to withstand the breaking stres
iven in the table, and no hemp is to be used in the strands, a hemp core only
) be fitted.

6. A short length of each of the wires composing the rigging will be required,
'ter being galvanised, to withstand a tensile stress equivalent to that set forth
ı the table, and the aggregate strength of the wires must not be less than
) per cent. in excess of that stress.

Wire Standing Rigging, etc., of Sailing Ships.

Tons 400 and under 500		Tons 300 and under 400	
6,200 and under 7,100		4,900 and under 6,200	
No.	Size in.	No.	Size in.
4	2¾	4	2½
	1¼		1¼
	7½ × 4½		7 × 4½
	3¾		3½
	1⅛		1⅛
	1		1
2	2¾	2	2⅛
	2		1¾
2	2¾	2	2¼
	2⅝		2⅛
	2		1¾
3	2⅜	3	2¼
	2⅜		2¼
	1⅜		1¼
	2⅜		2¼
	2⅜		2¼
	1⅜		1¼
	2		2
	1½		1½
	1 4/16		1 3/16
	9/16		9/16

Steel Wire Standing Rigging.					
Size	Weight per Fathom	Breaking Test	Size	Weight per Fathom	Breaking Test
in.	lb.	Tons	in.	lb.	Tons
5½	29·2	58	3⅛	9·30	17½
5¼	26·6	53	3	8·64	16
5	24·0	48	2⅞	7·90	14½
4⅞	23·4	44	2¾	7·30	13
4¾	22·0	42	2⅝	6·62	12
4⅝	20·75	40	2½	6·04	11
4½	19·5	38	2⅜	5·52	10
4⅜	18·5	36	2¼	4·84	9
4¼	17·5	34	2⅛	4·43	8
4⅛	16·4	32	2	3·84	7
4	15·4	30	1⅞	3·39	6
3⅞	14·5	28	1¾	2·92	5½
3¾	13·6	26	1⅝	2·54	5
3⅝	12·7	24	1½	2·17	4
3½	11·7	22	1⅜	1·80	3½
3⅜	10·9	20½	1¼	1·50	3
3¼	10·1	19			

Note.—The weights per fathom are not specified by Lloyd's, but are in accordance with information supplied by Messrs. R. S. Newall & Son, Glasgow.

7. Each wire will be required to be capable of being twisted around itself not less than eight times, and of being untwisted and straightened before breaking.

8. Where it is proposed to adopt iron wire rigging, the sizes proposed and the guaranteed tests should be submitted for the consideration of the Committee.

LLOYD'S RULES FOR THE CONSTRUCTION OF IRON AND STEEL MASTS, BOWSPRITS, AND YARDS.

1. If iron be used in the construction of masts, bowsprits, and yards, it is to be of good malleable quality, quite free from surface or other defects, and to stand a tensile strain of 20 tons to the sq. in. and the following bending tests when cold without fracture:—

Thickness of Plates	To Bend Cold through an Angle of	
	With the Grain	Across the Grain
[illegible]	23°	8°
[illegible]	30°	11°
[illegible]	37°	13°
[illegible]	47°	15°
[illegible]	55°	17°
[illegible]	63°	20°
[illegible]	70°	23°

2. The plates to be bent over a slab, the corner of which should be rounded with a radius of half an inch.

3. If steel be adopted, it is to be of the quality required for ship plates, and subjected to the same tests.

[illegible] ASTS.—The plating to be [illegible] s and the plates arranged [illegible] the table. The seams to [illegible] ed, in masts of less length [illegible] he edges may be single [illegible] ld angle bars be fitted to [illegible] n of the Committee. The [illegible] most partners in masts, [illegible] de the wedging of bow- [illegible] be double riveted, the [illegible] ald be treble riveted.

5. The butt straps to all masts should be 1-16th of an inch thicker than the plates they connect, in iron masts; in steel masts the butt straps should be 1-16th of an inch thicker than the plates in double-riveted butts, and 1-8th thicker in treble-riveted butts. The butt straps would be better to be fitted on the outside of the masts and bowsprit.

6. The mast and bowsprit plates should be doubled all round in way of the wedging, or otherwise efficiently strengthened; where masts are wedged at the lower deck, the doubling should extend from below the lower deck to above the upper deck.

7. The heels of all masts and their steps should be efficiently strengthened. The cheeks of masts should be stiffened by angles or cope iron on their foremost edges, or by some other approved plan.

8. Where two plates in the round are adopted instead of three, the iron is to be of such superior quality as to admit of its being bent to the required form without being unduly heated and without fracture, and in all such cases the masts should be additionally stiffened by three angles as provided for in the tables.

9. All masts of [illegible] feet length and above to be fitted with angles properly shifted and extending the whole length of the mast. If the plates be arranged as described in the tables, there should be an angle bar fitted to each plate in the round, of the size given in the table.

10. All bowsprits exceeding [illegible] inches in diameter should have a vertical diaphragm plate extending from within the wedging to the gammoning, connected by continuous single angle bars to the upper and lower parts of the bowsprit, and two additional angle bars of the size given in the table; and bowsprits [illegible] inches in diameter and under to have an angle bar at the centre of each plate extending the whole length of the bowsprit.

11. The diameter of the lower masts at the cap to be in no case less than that of the topmast at this place, or of the lower topsail yard.

12. The attention of the Surveyors is to be especially directed to the fittings connected with the masts and rigging, in order to insure the workmanship, material, and sizes of the same being efficient.

13. The mizenmasts for barques may be reduced one-fifth in diameter from that given in the table, and the plating to be not less than the thickness corresponding to the diameters.

14. Where a steamer is intended to be fitted with masts or a bowsprit for auxiliary purposes they may be one-eighth less in diameter than prescribed by table; and when a mast of a steamer is to carry fore and aft sail only the diameter may be one-fifth less than given in the table. The seams of these masts may be single riveted.

15. When pole masts are fitted, the length of the lower masts, in determining the diameter and thickness of plating, should be taken from the heel to the cap band, so as to include the head, as in an ordinary mast; and in sailing vessels these masts should be additionally strengthened by angles or otherwise, from below the lower yard to the topmast cap, or compensating strength furnished. The cheek plates in pole masts may be of the same thickness as the mast plates at the hounds.

16. The eye-bolts, hoops, cleats and bands are to be of the best description of wrought iron.

17. Any deviations from these rules and tables must be submitted for the consideration of the Committee.

Lloyd's Sizes for Bowsprits of Sailing Vessels and Full-rigged Steam Vessels.

IRON AND STEEL BOWSPRITS.

Length Outside Bed	Bed			Heel			Cap			Sizes of Angle Bars	
	Diameter	Thickness		Diameter	Thickness		Diameter	Thickness			
		Iron	Steel		Iron	Steel		Iron	Steel	Iron	Steel
Feet	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Inches	Inches
14	$16\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	14	$\frac{5}{16}$	$\frac{6}{20}$	12	$\frac{4}{16}$	$\frac{5}{20}$	$2\frac{1}{2} \times 2 \times \frac{5}{16}$	$2\frac{1}{2} \times 2 \times \frac{6}{20}$
15	$17\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	15	$\frac{5}{16}$	$\frac{6}{20}$	$12\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$2\frac{1}{2} \times 2 \times \frac{5}{16}$	$2\frac{1}{2} \times 2 \times \frac{6}{20}$
16	19	$\frac{5}{16}$	$\frac{6}{20}$	16	$\frac{5}{16}$	$\frac{6}{20}$	13	$\frac{5}{16}$	$\frac{6}{20}$	$3 \times 2 \times \frac{5}{16}$	$3 \times 2 \times \frac{6}{20}$
17	20	$\frac{6}{16}$	$\frac{7}{20}$	17	$\frac{6}{16}$	$\frac{7}{20}$	14	$\frac{5}{16}$	$\frac{6}{20}$	$3 \times 2 \times \frac{5}{16}$	$3 \times 2 \times \frac{6}{20}$
18	$21\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	18	$\frac{6}{16}$	$\frac{7}{20}$	15	$\frac{5}{16}$	$\frac{6}{20}$	$3 \times 2\frac{1}{2} \times \frac{5}{16}$	$3 \times 2\frac{1}{2} \times \frac{6}{20}$
19	23	$\frac{6}{16}$	$\frac{7}{20}$	19	$\frac{6}{16}$	$\frac{7}{20}$	16	$\frac{5}{16}$	$\frac{6}{20}$	$3 \times 3 \times \frac{6}{16}$	$3 \times 3 \times \frac{7}{20}$
20	$24\frac{1}{2}$	$\frac{7}{16}$	$\frac{8}{20}$	20	$\frac{6}{16}$	$\frac{7}{20}$	$16\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$3\frac{1}{2} \times 3 \times \frac{6}{16}$	$3\frac{1}{2} \times 3 \times \frac{7}{20}$
21	$25\frac{1}{2}$	$\frac{7}{16}$	$\frac{8}{20}$	21	$\frac{6}{16}$	$\frac{7}{20}$	$17\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$3\frac{1}{2} \times 3 \times \frac{6}{16}$	$3\frac{1}{2} \times 3 \times \frac{7}{20}$
22	$26\frac{1}{2}$	$\frac{7}{16}$	$\frac{8}{20}$	22	$\frac{6}{16}$	$\frac{7}{20}$	$18\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$4 \times 3 \times \frac{7}{16}$	$4 \times 3 \times \frac{8}{20}$
23	28	$\frac{8}{16}$	$\frac{9}{20}$	23	$\frac{7}{16}$	$\frac{8}{20}$	19	$\frac{6}{16}$	$\frac{7}{20}$	$4 \times 3\frac{1}{2} \times \frac{7}{16}$	$4 \times 3\frac{1}{2} \times \frac{8}{20}$
24	29	$\frac{8}{16}$	$\frac{9}{20}$	24	$\frac{7}{16}$	$\frac{8}{20}$	20	$\frac{6}{16}$	$\frac{7}{20}$	$4 \times 3\frac{1}{2} \times \frac{7}{16}$	$4 \times 3\frac{1}{2} \times \frac{8}{20}$
25	30	$\frac{8}{16}$	$\frac{9}{20}$	25	$\frac{7}{16}$	$\frac{8}{20}$	21	$\frac{6}{16}$	$\frac{7}{20}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{8}{16}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{9}{20}$
26	$31\frac{1}{2}$	$\frac{8}{16}$	$\frac{9}{20}$	26	$\frac{7}{16}$	$\frac{8}{20}$	$21\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{8}{16}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{9}{20}$
27	33	$\frac{8}{16}$	$\frac{9}{20}$	27	$\frac{7}{16}$	$\frac{8}{20}$	22	$\frac{6}{16}$	$\frac{7}{20}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{8}{16}$	$4\frac{1}{2} \times 3\frac{1}{2} \times \frac{9}{20}$

LLOYD'S SIZES AND SCANTLINGS FOR MASTS OF SAIL-

IRON AND

	Extreme Length *	Partners			Heel			Hounds			Head		
		Diameter	Thickness		Diameter	Thickness		Diameter	Thickness		Diameter	Thickness	
			Iron	Steel		Iron	Steel		Iron	Steel		Iron	Steel
	Feet	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Two Plates in the Round	48	16	$\frac{5}{16}$	$\frac{6}{20}$	13	$\frac{4}{16}$	$\frac{5}{20}$	$13\frac{1}{2}$	$\frac{4}{16}$	$\frac{5}{20}$	11	$\frac{3}{16}$	$\frac{3}{16}$
	51	17	$\frac{5}{16}$	$\frac{6}{20}$	$13\frac{1}{2}$	$\frac{4}{16}$	$\frac{5}{20}$	14	$\frac{4}{16}$	$\frac{5}{20}$	$11\frac{1}{2}$	$\frac{4}{16}$	$\frac{5}{20}$
	54	18	$\frac{5}{16}$	$\frac{6}{20}$	14	$\frac{4}{16}$	$\frac{5}{20}$	15	$\frac{4}{16}$	$\frac{5}{20}$	12	$\frac{4}{16}$	$\frac{5}{20}$
	57	19	$\frac{6}{16}$	$\frac{7}{20}$	15	$\frac{5}{16}$	$\frac{6}{20}$	$15\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$12\frac{1}{2}$	$\frac{4}{16}$	$\frac{5}{20}$
	60	20	$\frac{6}{16}$	$\frac{7}{20}$	16	$\frac{5}{16}$	$\frac{6}{20}$	$16\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$13\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$
	63	21	$\frac{6}{16}$	$\frac{7}{20}$	$16\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$17\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	14	$\frac{5}{16}$	$\frac{6}{20}$
	66	22	$\frac{6}{16}$	$\frac{7}{20}$	17	$\frac{5}{16}$	$\frac{6}{20}$	$18\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$	$14\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$
	69	23	$\frac{6}{16}$	$\frac{7}{20}$	18	$\frac{5}{16}$	$\frac{6}{20}$	19	$\frac{5}{16}$	$\frac{6}{20}$	$15\frac{1}{2}$	$\frac{5}{16}$	$\frac{6}{20}$
	72	24	$\frac{6}{16}$	$\frac{7}{20}$	19	$\frac{5}{16}$	$\frac{6}{20}$	20	$\frac{5}{16}$	$\frac{6}{20}$	16	$\frac{5}{16}$	$\frac{6}{20}$
Three Plates in the Round	75	25	$\frac{7}{16}$	$\frac{8}{20}$	$19\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	21	$\frac{6}{16}$	$\frac{7}{20}$	$16\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$
	78	26	$\frac{7}{16}$	$\frac{8}{20}$	20	$\frac{6}{16}$	$\frac{7}{20}$	$21\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	$17\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$
	81	27	$\frac{8}{16}$	$\frac{9}{20}$	21	$\frac{6}{16}$	$\frac{7}{20}$	$22\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	18	$\frac{6}{16}$	$\frac{7}{20}$
	84	28	$\frac{8}{16}$	$\frac{9}{20}$	22	$\frac{6}{16}$	$\frac{7}{20}$	23	$\frac{6}{16}$	$\frac{7}{20}$	$18\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$
	87	29	$\frac{8}{16}$	$\frac{9}{20}$	$22\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$	24	$\frac{6}{16}$	$\frac{7}{20}$	$19\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$
	90	30	$\frac{8}{16}$	$\frac{9}{20}$	23	$\frac{7}{16}$	$\frac{8}{20}$	25	$\frac{7}{16}$	$\frac{8}{20}$	20	$\frac{6}{16}$	$\frac{7}{20}$
	93	31	$\frac{9}{16}$	$\frac{10}{20}$	24	$\frac{7}{16}$	$\frac{8}{20}$	26	$\frac{7}{16}$	$\frac{8}{20}$	$20\frac{1}{2}$	$\frac{6}{16}$	$\frac{7}{20}$
	96	32	$\frac{9}{16}$	$\frac{10}{20}$	25	$\frac{7}{16}$	$\frac{8}{20}$	$26\frac{1}{2}$	$\frac{7}{16}$	$\frac{8}{20}$	21	$\frac{6}{16}$	$\frac{7}{20}$

* The length for regulating the scantlings of the mast to be taken,

ING VESSELS AND FULL-RIGGED STEAM VESSELS.

STEEL MASTS

Sizes of Angle Bars in Masts		Cheeks			
		Thickness of Plate		Sizes of Angle Bar	
Iron	Steel	Iron	Steel	Iron	Steel
Inches	Inches	Ins.	Ins.	Inches	Inches
—	—	$\frac{7}{16}$	$\frac{8}{20}$	$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{6}{16}$	$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{7}{20}$
—	—	$\frac{7}{16}$	$\frac{8}{20}$	$3\frac{1}{2} \times 3 \times \frac{6}{16}$	$3\frac{1}{2} \times 3 \times \frac{7}{20}$
—	—	$\frac{7}{16}$	$\frac{8}{20}$	$3\frac{1}{2} \times 3 \times \frac{6}{16}$	$3\frac{1}{2} \times 3 \times \frac{7}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4 \times 3 \times \frac{7}{16}$	$4 \times 3 \times \frac{8}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4 \times 3 \times \frac{7}{16}$	$4 \times 3 \times \frac{8}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4 \times 3 \times \frac{7}{16}$	$4 \times 3 \times \frac{8}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4\frac{1}{2} \times 3 \times \frac{7}{16}$	$4\frac{1}{2} \times 3 \times \frac{8}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4\frac{1}{2} \times 3 \times \frac{8}{16}$	$4\frac{1}{2} \times 3 \times \frac{9}{20}$
—	—	$\frac{8}{16}$	$\frac{9}{20}$	$4\frac{1}{2} \times 3 \times \frac{8}{16}$	$4\frac{1}{2} \times 3 \times \frac{9}{20}$
—	—	$\frac{9}{16}$	$\frac{10}{20}$	$5 \times 3 \times \frac{8}{16}$	$5 \times 3 \times \frac{9}{20}$
—	—	$\frac{9}{16}$	$\frac{10}{20}$	$5 \times 3 \times \frac{9}{16}$	$5 \times 3 \times \frac{10}{20}$
—	—	$\frac{9}{16}$	$\frac{10}{20}$	$5 \times 3\frac{1}{2} \times \frac{9}{16}$	$5 \times 3\frac{1}{2} \times \frac{10}{20}$
$3\frac{1}{2} \times 3 \times \frac{7}{16}$	$3\frac{1}{2} \times 3 \times \frac{8}{20}$	$\frac{10}{16}$	$\frac{11}{20}$	$5 \times 3\frac{1}{2} \times \frac{9}{16}$	$5 \times 3\frac{1}{2} \times \frac{10}{20}$
$4 \times 3 \times \frac{7}{16}$	$4 \times 3 \times \frac{8}{20}$	$\frac{10}{16}$	$\frac{11}{20}$	$5\frac{1}{2} \times 4 \times \frac{10}{16}$	$5\frac{1}{2} \times 4 \times \frac{11}{20}$
$4 \times 3 \times \frac{8}{16}$	$4 \times 3 \times \frac{9}{20}$	$\frac{10}{16}$	$\frac{11}{20}$	$6 \times 4 \times \frac{10}{16}$	$6 \times 4 \times \frac{11}{20}$
$4\frac{1}{2} \times 3 \times \frac{8}{16}$	$4\frac{1}{2} \times 3 \times \frac{9}{20}$	$\frac{11}{16}$	$\frac{12}{20}$	$6 \times 4 \times \frac{10}{16}$	$6 \times 4 \times \frac{11}{20}$
$5 \times 3 \times \frac{8}{16}$	$5 \times 3 \times \frac{9}{20}$	$\frac{11}{16}$	$\frac{12}{20}$	$6 \times 4 \times \frac{10}{16}$	$6 \times 4 \times \frac{11}{20}$

in all cases, from the cap to the top of the keelson.

Table giving Distances of Foreign Ports from London in Nautical Miles.

Aberdeen	433	Lizard	247
Aden	4,696 9,955	Madras	7,290 10,830
Alexandria	3,095	Malacca	8,737 12,237
Amsterdam	838	Malta	2,310
Antwerp	183	Manilla	9,650
Archangel	[illegible]	Mauritius	7,005
Auckland	916 120	Melbourne	11,360 11,635
Barbadoes	795	New Orleans	4,667
Barcelona	902	New York	3,245
Batavia (Java)	180 270	New Zealand	10,621 11,825
Bombay	390 10,695	Ostend	116
Bordeaux	650	Otago	12,190
Boston	3,025	Pekin (Gulf)	11,025 16,060
Bristol	584	Pernambuco	4,130
Buenos Ayres	6,240	Plymouth	315
Cadiz	1,322	Port Jackson	11,817 13,091
Calcutta	7,950 11,450	Portsmouth	195
Canton	10,468 13,563	Pulo Penang	8,858 11,893
Cape of Good Hope	6,065	Quebec	2,930
Cape Horn	7,396	Rangoon	6,025 11,590
Cardiff	517	Rio Janeiro	5,200
Charlestown	4,307	Rotterdam	185
Colombo (Ceylon)	6,796 10,885	San Francisco	13,670
Constantinople	3,065	Shanghai	10,545 13,680
Copenhagen	708	Sheerness	43
Cork	581	Shields	315
Dover	87	Sierra Leone	2,927
Dublin	580	Singapore	8,345 11,670
Dundee	420	Southampton	210
Ferrol	785	St. Helena	4,526
Funchal (Madeira)	1,297	St. Iago (Cape Verde Is.)	2,673
Gibraltar	1,330	St. John (Newfoundland)	2,099
Glasgow	785	St. Petersburg	1,687
Halifax	2,692	Stockholm	1,106
Hamburg	418	Swan River	10,428 11,638
Havanna	4,229	Sydney	10,840 12,044
Hobart Town	10,991 11,496	Teneriffe	1,730
Hong Kong	9,776 12,910	Venice	3,196
Hull	223	Washington	3,300
Kingston (Jamaica)	3,968	Waterford	608
Leghorn	2,268	Yokohama	11,340 14,670
Leith	418		
Lima	10,855		
Lisbon	1,053		
Liverpool	680		

PAINTS, VARNISHES, ETC.

PAINT ALLOWANCE.

Allowance per coat per 1,000 square yards.

1. *Outside surface.*

Grey.—White lead 200 lb., black paint 22 lb., dryers 15 lb., spirits of turpentine 15 pints, linseed-oil 45 pints.

White.—White lead 67 lb., zinc white 134 lb., dryers 15 lb., spirits of turpentine 15 pints, linseed-oil 50 pints.

Yellow.—Yellow ochre 150 lb., dryers 10 lb., spirits of turpentine 10 pints, linseed-oil 40 pints.

2. *Varnish and Inside Paint.*

Black.—Black paint 125 lb., dryers 10 lb., boiled linseed-oil 40 pints, linseed-oil 10 pints.

White.—White lead 67 lb., zinc white 133 lb., dryers 15 lb., spirits of turpentine 15 pints, linseed-oil 100 pints.

Red.—Venetian red paint 150 lb., dryers 10 lb., spirits of turpentine 10 pints, linseed-oil 40 pints.

Yellow.—English yellow paint 150 lb., remainder as red (above).

Green.—Green paint 170 lb., dryers 15 lb., boiled linseed-oil 40 pints, linseed-oil 40 pints, spirits of turpentine 5 pints.

Confined Spaces.—Iron oxide paint 280 lb., dryers 15 lb., boiled linseed-oil 60 pints, linseed-oil 40 pints.

Other internal portions.—Red lead paint 280 lb., white lead paint 70 lb., dryers 30 lb., boiled linseed-oil 60 pints, linseed-oil 40 pints.

Copal varnish for inside and outside.—200 pints.

White or grey enamel.—100 pints.

Flatting for grey enamel.—White lead 130 lb., ordinary block 15 lb., dryers 12½ lb., spirits of turpentine 32½ pints, linseed-oil 7½ pints.

Flatting for white enamel.—Zinc white 100 lb., white lead 50 lb., dryers 12½ lb., spirits of turpentine 30 lb., linseed-oil 7½ lb.

BITUMINOUS PAINT FOR ENGINE-ROOM AND BOILER-ROOM BILGES.

(Naval Constructor, H. Williams, U.S.N., A.S.N.E.)

Solution.—100 lb. coal-tar pitch and 50 lb. of Trinidad asphalt melted together. When cool add 65 lb. coal tar naphtha and 15 lb. of mineral oil.

Enamel.—350 lb. coal-tar pitch and 350 lb. Trinidad asphalt, melted together and boiled about 3 hours.

Cement.—150 lb. coal-tar pitch and 120 lb. Trinidad asphalt melted together and boiled about 3 hours; then add and stir in 150 lb. Portland cement.

First apply solution cold, after thoroughly cleaning the metal; 48 hours afterwards apply cement on horizontal and enamel on vertical surfaces. On overhead surface substitute ½ in. Portland cement for the enamel or cement. Both these last to be applied hot; the cement about ½ in. thick, the enamel (with a brush) $\frac{1}{16}$" to ⅛".

Good Dryers for Coloured Paints.

3 galls. of linseed oil, 1 lb. of manganese, 1 lb. of red lead, 1 lb of litharge. To be left for three hours.

Distemper.

112 lbs of whiting, 28 lbs of dry white lead, 7 lbs. of glue. To be mixed with boiling water.

Hammock Cloths.

46 lbs. black, 3½ galls. of boiled linseed oil.
2 lbs. litharge will paint about 100 yards running measure.
1 lb. white paint will cover about 3 square yards.
1 lb. black „ „ „ „ 6 „ „

Harmony of Colours.

Red looks well with white, black, or yellow.
Blue „ „ „ white or yellow.
Green „ „ „ black, white, or yellow.
Gold „ „ „ white, black, brown, blue, purple, and pink.

Mixing Paints.

White lead and lamp black mixed together make an ash colour.

White lead and ochre make the colour of new timber.
Yellow ochre and white lead make a buff colour.
White lead, vermilion, and lake make a flesh colour.
Lake and white make a carnation.
Yellow ochre and red lead make an orange.

Red lead, yellow ochre, and a little white make a brick-colour.

Burnt umber and white make a walnut-tree colour.

Yellow spruce, white lead, and a little black or burnt umber make a stone-colour.

This and experience will show the result of many other colours.

1 lb. of verdigris to 3 lbs. of white lead.
1 „ mineral „ 2 „ „ „
1 „ Antwerp „ $1\frac{1}{2}$ „ „ „

28 lbs of white lead 1 lb. of litharge 6 pints of linseed oil 2 „ turpentine	will cover about 100 superficial yards.
28 lbs. of black paint 1 lb. of litharge 10 pints of linseed oil 2 „ turpentine	will cover about 160 superficial yards.
46 lbs. of black $3\frac{1}{2}$ galls. of linseed oil 2 lbs. of litharge	will paint about 100 yards (running measure) of hammock cloths.

1 lb. of white paint will cover about 5 square yards.
1 lb. of black paint (thin) will cover about 7 square yards.

WEIGHT OF OAKUM AND PITCH, IN LBS., REQUIRED FOR EVERY 100 FEET OF SEAM IN LENGTH.

Materials	Decks	Top Sides	Wales, Channel, and Middle	Main Wales	Bottom
Oakum—					
Very slack seams	8	8	11	15	8
Ordinary slack seams	5	5	7	10	5
Pitch—					
Middling-sized seams	$24\frac{1}{2}$	$14\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$
Over spun-yarn when used	—	—	—	—	$9\frac{3}{4}$

OAKUM, PITCH, &c., FOR WOODWORK.

TABLE SHOWING THE QUANTITY AND DESCRIPTION OF OAKUM, &c., USED IN CAULKING 'NEW WORK' IN H.M. DOCKYARDS.

	Thickness of Plank	Double Threads of Oakum	Single Threads of Spun Yarn		Thickness of Plank	Double Threads of Black Oakum	Double Threads of White Oakum
Wales and bottom plank	Ins.			Topsides and waterways	Ins.		
	10	13 in No.	2 in No		9	11 in No.	—
	9	12 "	2 "		8	10 "	—
	8	11 "	2 "		7	9 "	—
	7	10 "	2 "		6	7 "	—
	6	8 "	2 "		5	5 "	1 in No.
	5	6 "	2 "		4	4 "	1 "
	4	5 "	2 "		3	3 "	1 "
	3	4 "	1 "		2½	2 "	1 "
	2½	3 "	—				
	2	2 "	—				
	1	1 "	—				
Gun decks	4	3 "	—		—	—	1 "
	3	2 "	—		—	—	1 "
		Single Threads of Black Oakum	**Single Threads of White Oakum**				
Weather decks	3	2 in No.	1 in No.				
	2½	2 "	1 "				
	2	1 "	1 "				

WEIGHT OF SPUN-YARN OF DIFFERENT SIZES, IN LBS., REQUIRED TO FILL EVERY 100 FT. OF SEAM IN LENGTH.

Materials	Number of Yarns					
	12	9	6	4	3	2
Spun-yarn . .	Lbs. 5¼	Lbs. 3¾	Lbs. 2½	Lbs. 1¾	Lbs. 1¼	Lb. ¼

Varnishes.

Black Japan for Metals.—Burnt umber 4 ozs., asphaltum 1½ oz., boiled oil 2 quarts. Mix by heat and thin with turpentine.

Another Recipe.—Amber 12 ozs., asphaltum 2 ozs. Fuse by heat; add boiled oil half a pint, resin 2 ozs.; when cooling add 16 ozs. of oil of turpentine.

Black Japan Varnish.—Bitumen 2 ozs., lamp-black 1 oz., Turkey umber ½ oz., acetate of lead ½ oz., Venice turpentine ½ oz., boiled oil 12 ozs. Melt the turpentine and oil together, carefully stirring in the rest of the ingredients, previously powdered. Simmer all together for ten minutes.

Cabinet-maker's Varnish.—Pale shellac 700 parts, mastic 65 parts, strongest alcohol 1,000 parts by measure. Dissolve and dilute with alcohol.

Cabinet Varnish.—Fused copal 14 lbs., hot linseed oil 1 gallon, hot turpentine 3 gallons. Properly boiled, dries very quickly.

Cheap Oak Varnish.—Dissolve 3½ lbs. of pale resin in 1 gallon of oil of turpentine.

Common Varnish.—Dissolve 1 part of shellac in 7 or 8 of alcohol.

Copal Varnish.—Copal 300 parts, drying linseed-oil 125 to 250 parts, spirit of turpentine 500 parts. Fuse the copal as quickly as possible; then add the oil, previously heated to nearly boiling-point; mix well; then cool a little and add the spirits of turpentine; again mix well, and cover up till it has cooled down to 130° Fahrenheit; then strain.

Copal Varnish for Metals, Chains, etc.—Copal melted and dropped into water 3 ozs., gum sandarach 6 ozs., mastic 2½ ozs., powdered glass 4 ozs., Ohio turpentine 2½ ozs., alcohol of 85 per cent. 1 quart. Dissolve by gentle heat.

Gold Varnish.—Turmeric 1 drachm, gamboge 1 drachm, oil of turpentine 2 pints, shellac 5 ozs., sandarach 5 ozs., dragon's blood 7 drachms, thin mastic varnish 8 ozs. Digest with occasional shaking for 14 days in a warm place; then set it aside to fine and pour off the clear.

Mastic Varnish.—Gum mastic 5 lbs., spirits of turpentine 2 gallons. Mix with gentle heat in a close vessel; then add pale turpentine varnish 3 pints.

Table Varnish.—Dammar resin 1 lb., spirits of turpentine 2 lbs., camphor 200 grains. Digest the mixture for 24 hours. The decanted portion is fit for immediate use.

Another Recipe.—Oil of turpentine 1 lb., bee's wax 2 ozs., colophony 1 drachm.

Turpentine Varnish.—Resin 1 part, boiled oil 1 part. Melt and then add turpentine 2 parts.

Varnish for Ironwork.—Dissolve 10 parts of clear grains of mastic, 5 parts of camphor, 15 parts of sandarach, and 5 parts of elemi in a sufficient quantity of alcohol, and apply cold.

Another Recipe.—Dissolve in about 2 lbs. of tar oil ½ lb. of asphaltum, ½ lb. of powdered resin. Mix hot in an iron kettle and apply cold.

Varnish for Metals.—Dissolve 1 part of bruised copal in 2 parts of strongest alcohol. It dries very quickly.

Another Recipe.—Copal 1 part, oil of rosemary 1 part, strongest alcohol 2 or 3 parts. This should be applied hot.

White Copal Varnish.—Copal 16 parts; melt, and add hot linseed oil 8 parts, spirits of turpentine 15 parts. Colour with the finest white lead.

White Priming for Japanning.—Parchment size ⅔, isinglass ⅓.

White Varnish.—Tender copal 7½ ozs., camphor 1 oz., alcohol of 95 per cent. 1 quart; dissolve, then add 2 ozs. of mastic, 1 oz. of Venice turpentine; again dissolve, and strain.

White Spirit Varnish.—Sandarach 25 parts, mastic in tears 6 parts, strongest alcohol 100 parts, elemi 3 parts, Venice turpentine 6 parts. Dissolve in closely corked vessel.

LACQUERS.

To make Lacquer.—Mix the ingredients and let them stand in a warm place for 2 or 3 days, shaking them freely till the gum is dissolved, after which let them settle for 48 hours, when the clear liquor may be poured off ready for use. Pulverised glass is sometimes used to carry off impurities.

Gold Lacquer.—Ground turmeric 1 lb., gamboge 1½ oz., powdered gum sandarach 3½ lbs., shellac ¾ lb., spirits of wine 2 gallons. Shake till dissolved, then strain and add 1 pint of turpentine varnish.

Gold Lacquer for Brass not Dipped.—Alcohol 4 gallons, turmeric 3 lbs., gamboge 3 ozs., gum sandarach 7 lbs., shellac 1½ lb., turpentine varnish 1 pint.

Gold Lacquer for Dipped Brass.—Alcohol 36 ozs., seed-lac 6 ozs., amber 2 ozs., gum gutta 2 ozs., red sandal-wood 24 grains, dragon's blood 60 grains, Oriental saffron 36 grains, pulverised glass 4 ozs.

Good Lacquer.—Alcohol 8 ozs., gamboge 1 oz., shellac 3 ozs., annotto 1 oz., solution of 3 ozs. of seed-lac in 1 pint of alcohol; when dissolved, add Venice turpentine ½ oz., dragon's blood ¼ oz. Keep in a warm place 4 or 5 days.

Good Lacquer for Brass.—Seed-lac 6 ozs., amber or copal 2 ozs., best alcohol 4 gallons, pulverised glass 4 ozs., dragon's blood 40 grains, extract of red sandal-wood obtained by water 30 grains.

Lacquer for Dipped Brass.—Alcohol of 95 per cent. 2 gal-

ions, seed-lac 1 lb., gum copal 1 oz., English saffron 1 oz., annotto 1 oz.

Another Recipe.—Alcohol 12 gallons, seed-lac 9 lbs., turmeric 1 lb. to a gallon of the above mixture, Spanish saffron 4 ozs. The saffron is only to be added for bronze work.

Lacquer Varnish.—Add so much turmeric and annotto to lac varnish as will give the proper colour, and squeeze through a cloth.

Pale Lacquer for Brass.—Alcohol 8 gallons, dragon's blood 4 lbs., Spanish annotto 12 lbs., gum sandarach 13 lbs., turpentine 1 gallon.

Dipping Acids.

Aquafortis Bronze Dip.—Nitric acid 8 ozs., muriatic acid 1 quart, sal ammoniac 2 ozs., alum 1 oz., salt 2 ozs., water 2 gallons. Add the salt after boiling the other ingredients, and use it hot.

Brown Bronze Dip.—Iron scales 1 lb., arsenic 1 oz., muriatic acid 1 lb.; a piece of solid zinc, 1 oz. in weight, to be kept in while using.

Brown Bronze Paint for Copper Vessels.—Tincture of steel 4 ozs., spirits of nitre 4 ozs., essence of dendi 4 ozs., blue vitriol 1 oz., water ½ pint. Mix in a bottle. Apply it with a fine brush, the vessel being full of boiling water. Varnish after the application of the bronze.

Bronze for all kinds of Metals.—Muriate of ammoniac (sal ammoniac) 4 drachms, oxalic acid 1 drachm, vinegar 1 pint. Dissolve the oxalic acid first.

Dipping Acid.—Sulphuric acid 12 lbs., nitric acid 1 pint, nitre 4 lbs., soot 2 handfuls, brimstone 2 ozs. Pulverise the brimstone and soak it in water 1 hour; add the nitric acid last.

Another Recipe.—Sulphuric acid 4 gallons, nitric acid 2 gallons, saturated solution of sulphate of iron (copperas) 1 pint, solution of sulphate of copper 1 quart.

Good Dipping Acid for Cast Brass.—Equal quantities of sulphuric acid, nitre, and water. A little muriatic acid may be added.

Green Bronze Dip.—Wine vinegar 2 quarts, verditer green 2 ozs., sal ammoniac 1 oz., salt 2 ozs., alum ½ oz., French berries 8 ozs. Boil the ingredients together.

Ormolu Dipping Acid for Sheet Brass.—Sulphuric acid 2 gallons, nitric acid 1 pint, muriatic acid 1 pint, water 1 pint, nitre 12 lbs. Put in the muriatic acid last, adding a little at a time, and stir with a stick.

Another Recipe.—Sulphuric acid 1 gallon, sal ammoniac 1 oz.,

flowers of sulphur 1 oz., blue vitriol 1 oz., saturated solution of zinc in nitric acid mixed with equal quantity of sulphuric acid 1 gallon.

Vinegar Bronze for Brass.—Vinegar 10 gallons, blue vitriol 3 lbs., muriatic acid 3 lbs., corrosive sublimate 4 grains, sal ammoniac 2 lbs., alum 8 ozs.

Cements and Glues.

Cement for Earthen and Glass Ware.—Isinglass dissolved in proof spirit and soaked in water 2 ozs. (thick); dissolve in this 10 grains of very pale gum ammoniac (in tears) by rubbing them together, then add 6 large tears of gum mastic dissolved in the least possible quantity of rectified spirit.

Cement for Iron Tubes, &c.—Finely powdered iron 60 parts, sal ammoniac 1 pint, sufficient water to form into a paste.

Cement for Plumbers.—Black resin 1 part, brick dust 2 parts. Melt together.

Cement for Leaky Boilers.—Powdered litharge 2 parts, fine sand 2 parts, slaked lime 1 part.

Cement for Joining Metals and Wood.—Stir calcined plaster into melted resin until reduced to a paste; add boiled oil till brought to the consistency of honey. Apply warm.

Cast-iron Cement.—Clean iron borings or turnings pounded and sifted 50 to 100 parts, sal ammoniac 1 part. When it is to be applied moisten it with water.

Turner's Cement.—Bee's wax 1 oz., resin ½ oz., pitch ½ oz. Melt and stir in fine brick dust.

Coppersmith's Cement.—Powdered quick lime mixed with bullock's blood and applied immediately.

Engineer's Cement.—Equal weights of red and white lead mixed with drying oil. Spread on tow or canvas.

Cement for Joining Metal and Glass.—Copal varnish 15 parts, drying oil 5 parts, turpentine 3 parts, oil of turpentine 2 parts, liquid glue 5 parts. Melt in a bath and add 10 parts of slaked lime.

Gasfitter's Cement.—Resin 4½ parts, wax 1 part, Venetian red 1 part.

Cement for Fastening Blades into Handles.—Shellac 2 parts, prepared chalk 1 part, powdered and mixed.

Cement for Pots and Pans.—Partially melt 2 parts of sulphur and add 1 part of fine blacklead. Mix well. Pour on stone to cool, and then break it in pieces. Use like solder with an iron.

Cement for Cracks in Stoves.—Finely pulverised iron made into a thick paste with water glass.

Very Strong Glue.—Mix a small quantity of powdered chalk with melted common glue.

Glue to Resist Moisture.—Boil 1 lb. of common glue in 2 quarts of skimmed milk.

Marine Glue.—Cut caoutchouc 4 parts into small pieces and dissolve it by heat and agitation in 34 parts of coal naphtha, add to this solution 64 parts of powdered shellac, and heat the whole with constant stirring until combination takes place, then pour while hot on to metal plates to form sheets. When used must be heated to 280° Fahr.

Liquid Glue.—Dissolve 1 part of powdered alum in 120 parts of water; add 120 parts of glue, 10 parts of acetic acid, and 40 parts of alcohol. Digest.

Another Recipe.—Dissolve 2 lbs. of good glue in 2⅛ pints of hot water, add gradually 7 ozs. nitric acid, and mix well.

Parchment Glue.—Parchment shavings 1 lb., water 6 quarts; boil until dissolved, then strain and evaporate slowly until of proper consistency.

Draughtsman's or Mouth Glue.—Glue 5 parts, sugar 2 parts, water 8 parts. Melt in water bath and cast in moulds. For use dissolve in warm water or moisten in the mouth.

WOOD-STAINING.

Mahogany Colour (Dark).—Boil together in a gallon of water ½ lb. of madder and 2 ozs. of logwood. When the wood is dry, after having been washed over with the hot liquid, go over again with a solution of 2 drachms of pearl ash in a quart of water.

Mahogany Colour (Light).—Wash the surface with diluted nitrous acid, and when dry use the following:—dragon's blood 4 ozs., common soda 1 oz., spirits of wine 3 pints. When well dissolved, strain.

Rose Wood.—Boil 8 ozs. of logwood in 3 pints of water until it is reduced to half. Apply boiling hot two or three times. The stain for the streaks is made from a solution of copperas and verdigris in a decoction of logwood.

Ebony.—Wash the wood with a solution of sulphate of iron; when dry, apply a mixture of logwood and nut galls; when dry, wipe with a sponge and polish with linseed oil.

ENAMELS.

White Enamel.—Potash 25 parts, arsenic 14 parts, glass 13 parts, saltpetre 12 parts, flint 5 parts, and litharge 3 parts.

Black Enamel.—Clay 2 parts, protoxide of iron 1 part.

Blue Enamel.—Fine paste 10 parts, nitre 3 parts; colour with cobalt.

Green Enamel.—Frit 1 lb., oxide of copper $\frac{1}{2}$ oz., red oxide of iron 12 grs.

Yellow Enamel.—White lead 2 parts; alum, white oxide of antimony, and sal ammoniac, each 1 part.

Tracing Paper.

Nut oil 4 parts, turpentine 5 parts; mix and apply to the paper, then rub dry with flour and brush it over with ox gall.

Indian Ink.

Finest lamp black made into a thick paste with thin isinglass or gum water, and moulded into shape. It may be scented with essence of musk.

Copying Ink.

Add 1 oz. of moist sugar or gum to every pint of common ink.

Staircases or Companion Ladders.

The ordinary tread of a stair or step is 8 ins., and rise $7\frac{1}{2}$ ins.; above or below that $\frac{1}{2}$ in. rise must be subtracted or added for every inch added to or taken from the width of tread, as the case may be.

Cask-Gauging.

C = contents of cask in gallons.

D = middle or bung diameter in ins

L = length in ins.

d = end or head diameter in ins.

$$C = \cdot0009442L(2D^2 + d^2) \text{ considerably curved.}$$

$$C = \cdot0009442L(2D^2 + d^2) - \tfrac{2}{5}(D - d)^2 \text{ moderately curved.}$$

$$C = \cdot0014132L(D^2 + d^2) \text{ very little curve.}$$

$$C = \cdot0000315L(39D^2 + 25d^2 + 26Dd) \text{ any form.}$$

Variations of Tides.

The difference in time between high water and high water averages about 49 minutes.

GALVANISING IRON ARTICLES.

1. *Cleaning the Work.*—Any paint or old work should be burnt off before being placed in the acid bath.

2. The acid bath for cleaning the work should consist of water 40 parts, muriatic acid 1 part.

3. Two or three hours in the acid bath will remove dirt and oxide. Cast articles generally require longer time than wrought. Work put in at night may remain without injury till the next morning.

4. When the bath ceases to act fresh acid should be added till it acts as at first. If the acid solution has become thick from the work, it should be allowed to settle, and the clear liquid syphoned off, the bath cleansed, and the liquid again returned.

5. When the work is removed from the acid bath it should be washed in water, and all dirt or oxide removed by brushing or scouring. It should then be placed for two or three minutes in a bath composed of water 6 parts, muriatic acid 1 part. On removal from this bath it should be placed in a clean, warm place to dry.

6. As far as practicable the work should be taken warm from the drying-furnace to the zinc bath. It should be lowered endways slowly into the molten zinc, so as to remove any loose oxide or air from the surface, and allowed to remain long enough to become as hot as the zinc. When it is considered this has been effected it should be raised slowly; if the zinc does not completely cover and flow freely over and from the surface, it must be again lowered and allowed to remain longer. On its final removal some powdered sal-ammoniac should be thrown from the hand on the surface, which greatly helps to make the surface smooth and remove the surplus zinc. When this is done the work should be put aside to cool gradually. It must not be dipped in water when hot, nor chilled in cold air. Articles with joints should be worked whilst cooling, to prevent being set fast.

ZINC BATH.

1. The metal must never be allowed to cool and set fast in the bath.

2. At night the bath should be covered by a sheet of iron, to prevent loss of heat, the fire made up, and again seen to once in the night.

3. When from want of work the operation is to be suspended for a time, the zinc should be ladled out into ingots or cakes. In the case of small baths this is done every night to save attention and fuel in the night.

4. The zinc bottoms which form in the bath should be raked out as soon as they form to the depth of two inches in a large bath or one inch in a small one; and in dipping articles care should be taken not to lower them down far enough to touch the zinc bottoms.

ENGLISH WEIGHTS AND MEASURES.

AVOIRDUPOIS WEIGHT.

Drams	Ozs.	Lbs.	Qrs.	Cwts.	Ton	Grammes
1	·0625	·0039063	·0001395	·0000349	·00000174	1·771846
16	= 1	·0625	·0022321	·000558	·00002790	28·34954
256	16	= 1	·0357143	·0089285	·00044643	453·5927
7168	448	28	= 1	·25	·0125	12700·59
28672	1792	112	4	= 1	·05	50802·38
573440	35840	2240	80	20	= 1	1016048

A stone of iron, coal, &c. = 14 lbs.

TROY WEIGHT.

Avoir. Drs.	Grains	Dwts.	Ozs.	Lbs.	Grammes
32 ÷ 875	= 1	·0416667	·0020833	·0001736	·0648
768 ÷ 875	24	= 1	·05	·0041667	1·5552
17 + (97 ÷ 175)	480	20	= 1	·0833333	31·1035
210 + (114 ÷ 175)	5760	240	12	= 1	373·2420

175 lbs. Troy = 144 lbs. Avoir. 175 oz. Troy = 192 oz. Avoir.
Avoir. lbs. × 1·21527 = lbs. Troy. Troy lbs. × ·823 = Avoir. lbs.

In the "Apothecaries'" system the pound, the ounce (℥) and the grain are the same as in the "Troy" system; but other subdivisions are different; e.g. 20 grains make 1 scruple (℈), 8 scruples make 1 dram (ʒ), and 8 drams make 1 ounce.

LINEAL MEASURE.

Inches	Feet	Yards	Faths.	Poles	Furls.	Mile	Metres
1	·08333	·02778	·013889	·005051	·000126	·000016	·0254
12	= 1	·33333	·166667	·060606	·001515	·000189	·304797
36	3	= 1	·5	·181818	·004545	·000568	·914392
72	6	2	= 1	·363636	·009091	·001136	1·82878
198	16½	5½	2¾	= 1	·025	·003125	5·02915
7920	660	220	110	40	= 1	·125	201·166
63360	5280	1760	880	320	8	= 1	1609·33

The palm = 3 in. The hand = 4 in.
The span = 9 in. The cubit = 18 in.
The common military pace = 30 in. An itinerary pace = 5 feet.
A cable's length = 120 fathoms. A league = 3 miles.

LAND MEASURE (LINEAL).

Inches	Links	Feet	Yards	Chains	Mile	Metres
1	·1261261	·0833333	·0277778	·0012626	·0000158	·0254
$7\frac{23}{25}$	= 1	·6666667	·2222222	·01	·000125	·201166
12	$1\frac{17}{33}$	= 1	·3333333	·0151515	·0001894	·304797
36	$4\frac{6}{11}$	3	= 1	·0454545	·0005682	·914392
792	100	66	22	= 1	·0125	20·1166
63360	8000	5280	1760	80	= 1	1609·33

Square Measure.

Inches	Feet	Yards	Perches	Roods	Acre	Sq. Metres
1	·0069444	·0007716	·0000255	·00000064	·00000016	·0006452
144	=1	·1111111	·0036731	·0000918	·000023	·0929013
1296	9	=1	·0330579	·0008264	·0002066	·836112
39204	272¼	30¼	=1	·025	·00625	25·292
1568160	10890	1210	40	=1	·25	1011·696
6272640	43560	4840	160	4	=1	4046·782

Acres × ·0015625 = sq. miles. Sq. yards × ·000000323 = sq. miles.

Land Measure (Square).

Links	Perches	Chains	Roods	Acre	Sq. Metres
1	·0016	·0001	·00004	·00001	·04046
625	=1	·0625	·025	·00625	25·292
10000	16	=1	·4	·1	404·6782
25000	40	2½	=1	·25	1011·696
100000	160	10	4	=1	4046·782

A hide of land = 100 acres. A yard of land = 30 acres.
A chain wide = 8 acres per mile.

Cubic Measure.

Imperial Gallons	Cub. Ins.	Cub. Feet	Cub. Yds.	Cub. Metre
·003606540822	=1	·0005788	·00000214	·000016387
6·232102541168	1728	=1	·0370370	·0283161
168·266768641554	46656	27	=1	·764534

A cubic yard of earth = 1 load. A barrel bulk = 5 cub. ft.
Ton of displacement of a ship = 35 cub. ft. = ·9910624 cub. metre.

Wine Measure.

Cub. Ins.	Gills	Pints	Quarts	Gallons	Ankers	Runlets	Barrels	Tierces	Hogsheads	Puncheons	Pipes or Butts	Tun
8·664 13/16	=1											
34·659¼	4	=1										
69·318½	8	2	=1									
277·274	32	8	4	=1								
2772·740	320	80	40	10	=1							
4990·932	576	144	72	18	1⅘	=1						
8734·131	1008	252	126	31½	3 3/20	1¾	=1					
11645·508	1344	336	168	42	4⅕	2⅓	1⅓	=1				
17468·262	2016	504	252	63	6 3/10	3½	2	1½	=1			
23291·016	2688	672	336	84	8⅖	4⅔	2⅔	2	1⅓	=1		
34936·524	4032	1008	504	126	12⅗	7	4	3	2	1½	=1	
69873·048	8064	2016	1008	252	25⅕	14	8	6	4	3	2	=1

One gallon of water weighs 10 lbs. 20 fluid ozs. make 1 pint.

Ale and Beer Measure.

Cub. Ins.	Pints	Quarts	Gallons	Firkins	Kilderkins	Barrels	Hogsheads	Puncheons	Butts	Tuns	Last
34·659¼	=1										
69·318½	2	=1									
277·274	8	4	=1								
2495·466	72	36	9	=1							
4990·932	144	72	18	2	=1						
9981·864	288	144	36	4	2	=1					
14972·796	432	216	54	6	3	1½	=1				
19963·728	576	288	72	8	4	2	1⅓	=1			
29945·592	864	432	108	12	6	3	2	1½	=1		
59891·184	1728	864	216	24	12	6	4	3	2	=1	
119782·368	3456	1728	432	48	24	12	8	6	4	2	=1

Corn and Dry Measure.

Cub. Ins.	Pints	Quarts	Pottles	Gallons	Pecks	Bushels	Strikes	Sacks	Quarters	Loads	Last
34·659¼	=1										
69·318½	2	=1									
138·637	4	2	=1								
277·274	8	4	2	=1							
554·548	16	8	4	2	=1						
2218·192	64	32	16	8	4	=1					
4436·384	128	64	32	16	8	2	=1				
8872·768	256	128	64	32	16	4	2	=1			
17745·536	512	256	128	64	32	8	4	2	=1		
88727·680	2560	1280	640	320	160	40	20	10	5	=1	
177455·360	5120	2560	1280	640	320	80	40	20	10	2	=1

Coal Measure.

Cub. Ins. Heaped Measure	Lbs. Avoir.	Pecks	Bushels	Sacks	Vats or Strikes	Chalds.	Newc. Chalds.	Keels	Scores	Ship Load
703·872	18⅔	=1								
2815·487	74⅔	4	=1							
8446·461	224	12	3	=1						
25339·383	672	36	9	3	=1					
101357·532	2688	144	36	12	4	=1				
196380·218¼	5208	279	69¾	23¼	7¾	$1\frac{15}{16}$	=1			
1571041·746	41664	2232	558	186	62	15½	8	=1		
2128508·172	56448	3024	756	252	84	21	$10\frac{26}{31}$	$1\frac{11}{31}$	=1	
31420834·92	833280	44640	11160	3720	1240	310	160	20	$14\frac{16}{21}$	=1

Wool Weight.

Pounds	Cloves	Stones	Tods	Weys	Packs	Sacks	Last
7	=1						
14	2	=1					
28	4	2	=1				
182	26	13	$6\frac{1}{2}$	=1			
240	$34\frac{2}{7}$	$17\frac{1}{7}$	$8\frac{4}{7}$	$1\frac{29}{91}$	=1		
364	52	26	13	2	$1\frac{31}{60}$	=1	
4368	624	312	156	24	$18\frac{1}{5}$	12	=1

Measure of Time.

Seconds	Minutes	Hours	Days	Weeks	Months	Calend. Year	Julian Year	Leap Year
60	=1							
3600	60	=1						
86400	1440	24	=1					
604800	10080	168	7	=1				
2419200	40320	672	28	4	=1			
31536000	525600	8760	365	$52\frac{1}{7}$	$13\frac{1}{28}$	=1		
31557600	525960	8766	$365\frac{1}{4}$	$52\frac{5}{8}$	$13\frac{5}{112}$	$1\frac{1}{1460}$	=1	
31622400	527040	8784	366	$52\frac{2}{7}$	$13\frac{1}{14}$	$1\frac{1}{365}$	$1\frac{1}{487}$	=1

Angular Measure.

The Geographical Division of any Line round the Circumference of the Earth	Diurnal Motion of the Earth reduced to Time
60 seconds = 1 minute	= 4 seconds
60 minutes = 1 degree	= 4 minutes
15 degrees = ½ sign of the zodiac . . .	= 1 hour
30 degrees = 1 sign of the zodiac . . .	= 2 hours
90 degrees = 1 quadrant	= 6 hours
1 revolution or 4 quadrants or 360 degrees = the earth's circumf., or 12 signs = 1 great circle .	= 24 hours

Coke.

4 bushels = 1 sack. 12 sacks = 1 chaldron. 21 chaldrons = 1 score.

Miscellaneous Weights and Measures.

Aume of hock . . . . 31 gals.
Bag of cocoa . . . . 112 lbs.
" coffee . . . . 140 to 168 "
" hops . . . . 280 "
" pepper (black), company's . . . . . . 316 "
" " free-trade bags . . . 28, 56, and 112 "
" " (white) . . . . 168 "
" rice . . . . 168 "
" sago . . . . 112 "

MISCELLANEOUS WEIGHTS AND MEASURES (continued).

Bag of saltpetre (East India)	168 lbs.
„ sugar or malt (Mauritius)	112 to 168 „
„ „ (East India)	112 to 196 „
„ biscuits (Admiralty)	102 „
Bale of coffee (Mocha)	224 to 280 „
„ cotton wool (Virginia, Carolina, & W. Indies)	300 to 310 „
„ „ „ (New Orleans and Alabama)	400 to 500 „
„ „ „ (East India)	320 to 360 „
„ „ „ (Brazil)	160 to 200 „
„ „ „ (Egyptian)	180 to 280 „
„ rags (Mediterranean)	448 to 476 „
Bar of bullion	15 to 30 „
Barrel of raisins	112 „
„ soap	256 „
„ anchovies	30 „
„ coffee	112 to 168 „
„ tar	26·5 gals.
„ turpentine	224 to 280 lbs.
„ flour	220 „
„ pork	224 „
Boll of flour	140 „
Box of camphor	112 „
„ raisins (Valencia)	30 to 40 „
Bushel of wheat	60 „
„ flour	56 „
„ rye	58 „
„ barley	47 „
„ oats	40 „
„ oatmeal	51 „
„ peas	64 „
„ beans	63 „
„ rape seed	50 „
„ malt	38 „
„ salt	56 „
„ clover (red)	64 „
„ „ (white)	62 „
„ linseed	52 „
„ chicory (raw)	50 „
„ „ (kiln-dried)	28 „
„ „ (powdered)	38 „
„ coffee (raw)	51·25 „
„ „ (roasted)	32·25 „
„ „ (ground)	36 „
„ buck wheat	50 to 56 „
„ canary seed	53 to 61 „
„ hemp „	42 to 44 „
„ lentil „	60 to 62 „
„ linseed (Bombay)	50 to 52 „

MISCELLANEOUS WEIGHTS AND MEASURES (continued).

Bushel of onion seed	36 to 38 lbs.
„ millet „	56 to 64 „
„ poppy „	48 „
„ rape „	48 to 53 „
„ tare „	62 to 66 „
„ turnip „	50 to 56 „
„ cabbage „	50 to 56 „
Butt of currants	1,680 to 2,240 „
„ cadiz	108 gals.
„ sherry	108 „
Cask of cocoa	140 lbs.
„ mustard	9 to 18 „
„ nutmegs	200 „
„ rice (American)	672 „
„ tallow	1,008 „
Catty of tea	1·33 „
Chaldron of coals	2·63 tons
Chest of tea (Congou) about	82·5 lbs.
„ „ (Souchong) „	81·0 „
„ „ (Pekoe) „	65·5 „
„ „ (Hyson and Hyson skin) about	65 „
„ „ (Gunpowder) about	109 „
„ „ (Imperial) about	95·7 „
„ „ (Young Hyson)	94 „
Cran of herrings	37·5 gals.
Firkin of butter	56 lbs.
„ soap	64 „
Hogshead of brandy	45 to 60 gals.
„ „ rum	45 to 50 „
„ „ tobacco	1,344 to 2,016 lbs.
„ „ sugar	1,456 to 1,792 „
„ „ whisky	55 to 60 gals.
„ „ burgundy	44 „
„ „ claret	46 „
„ „ lisbon	58 „
„ „ port	57 „
„ „ sherry	54 „
Jar of olive oil	25 „
Last of salt	18 barrels
„ potash, cod fish, herrings, meal, soap, tar	12 „
„ flax or feathers	1,904 lbs.
„ ale or beer	12 barrels
„ gunpowder	24 „
Load of hay or straw	36 trusses
„ bricks	500 number
„ tiles	1,000 „
Pig of ballast	56 lbs.
Pipe of Cape wine	92 gals.
„ Lisbon or Bucellas	117 „

MISCELLANEOUS WEIGHTS AND MEASURES (concluded).

Pipe of madeira	110 gals.
„ malaga	105 „
„ marsala	108 „
„ port	113 to 115 „
„ sherry or tent	92 to 108 „
„ teneriffe or vidonia	100 „
Pocket of hops	168 to 224 lbs.
Puncheon of brandy	110 to 120 gals.
„ „ rum	90 to 100 „
„ „ whisky (Scottish)	112 to 130 „
„ „ prunes	1,120 lbs.
„ „ molasses	1,120 to 1,344 „
Quintal of fish	112 „
Roll of parchment	60 skins
Sack of coals	224 lbs.
„ flour of 2 bolls	280 „
Tierce of beef (Irish) of 38 pieces	304 „
„ coffee	560 to 784 „
„ pork (Irish) of 80 pieces	320 „
Truss of straw	36 „
„ old hay	56 „
„ new hay	60 „
Tub of butter	84 „
Tun of oil (wine gals.)	252 gals.

MISCELLANEOUS NUMBERS.

12 units	make	1 dozen
13 units	„	1 long dozen
12 dozen	„	1 gross
12 gross, or 144 dozen	„	1 great gross
20 units	„	1 score
21 units	„	1 long score
5 score, or 100	„	1 short hundred
6 score, or 120	„	1 long hundred
24 sheets	„	1 quire of paper or parchment
20 sheets	„	1 quire of outside
25 sheets	„	1 printer's quire
20 quires, or 472 sheets	„	1 ream of ditto or parchment
21½ quires, or 516 sheets	„	1 perfect or printer's ream
2 reams	„	1 bundle of ditto
10 reams, or 200 quires	„	1 bale
5 doz., or 60 skins, of parchment	„	1 roll
4 pages, or 2 leaves	„	1 sheet of folio
8 pages, or 4 leaves	„	1 sheet of quarto or 4to.
16 pages, or 8 leaves	„	1 sheet of octavo or 8vo.
24 pages, or 12 leaves	„	1 sheet of duodecimo or 12mo.
36 pages, or 18 leaves	„	1 sheet of eighteens or 18mo.
72 words in common law	„	1 sheet
80 words in exchequer	„	1 sheet
90 words in chancery	„	1 sheet

Sizes and Contents of Casks.

Sundry Casks	Lgth. (ins.)	Diam. (ins.)	Contents (gals.)	Admiralty Casks	Lgth. (ins.)	Diam. (ins.)	Contents (gals.)
Marsala pipe .	65	32	108	Leager . .	59	38	164
„ hhd. .	41	25	45·5	Butt . .	53	33	110
Brandy pipe .	52	34	114	Puncheon .	41½	30	72
„ hhd. .	40	28	57·5	Hogshead .	37	28	54
Port pipe .	58	34	113	Barrel . .	31½	24·5	36
„ hhd. .	37	30	56·5	Half-hogshead	28	22·5	27
Sherry butt .	50	35	108	Kilderkin .	25	19·75	18
„ hhd. .	38	28	54·5	Firkin . .	22	17	12
Rum puncheon	42	36	91				

Size of Drawing Papers.

	Inches		Inches
Antiquarian . .	53 × 31	Royal . . .	24 × 19
Double elephant .	40 × 27	Medium . . .	22 × 17
Atlas	34 × 26	Demy . . .	20 × 15
Colombier . . .	34 × 23	Foolscap . . .	17 × 13½
Imperial . . .	30 × 22	Tracing papers . .	30 × 20
Elephant . . .	28 × 23	Ditto . . .	30 × 40
Super royal . .	27 × 19	Ditto . . .	60 × 40

Continuous tracing paper, 28, 31, 40, 44, and 56 in. wide by 21 yards long.
Continuous tracing linen, 18, 28, 36, 38, and 41 in. wide by 24 yards long.
Continuous drawing cartridge, 54, 57, 58, and 60 in. wide by 50 yards long.

METRICAL SYSTEM.

Long Measure (1).

	Metres	Inches	Feet	Yards	Miles
Millimetre .	= ·001	·03937	·00328	·00109	—
Centimetre .	·01	·39370	·03281	01094	·000006
Decimetre .	·1	3·93704	·32809	·10936	·000062
Metre[1] . .	1	39·37043	3·28087	1·09362	·000621
Decametre .	10	393·7043	32·80869	10·93623	·006214
Hectometre .	100	3937·043	328·08693	109·36231	·062138
Kilometre .	1000	39370·43	3280·8693	1093·6231	·621377
Myriametre .	10000	393704·3	32808·693	10936·231	6·213768

Square Measure.

	Sq. Metres	Sq. Inches	Sq. Feet	Sq. Yards	Acres
Milliare .	= ·1	155	1·076	·119601	·0000247
Centiare .	1	1550	10·764	1·19601	·0002471
Deciare .	10	15500	107·641	11·9601	·0024711
Are[2] . .	100	155003	1076·410	119·601	·0247110
Decare . .	1000	1550031	10764·104	1196·01	·2471098
Hectare .	10000	15500309	107641·04	11960·12	2·4710981

[1] See Long Measure, next page.

[2] The are = the square decametre.

LONG MEASURE (2).

	Inches and Decimals of an In	Miles	Furls.	Poles	Yards	Feet	Inches and Fractions of an Inch
Millimetre .	= ·0394	......	......	......	......	......	...... $\frac{1}{32}$ ... $\frac{1}{128}$ −
Centimetre	·3937	......	......	......	......	......	... $\frac{3}{8}$ ... $\frac{1}{64}$ ... −
Decimetre .	3·9370	......	......	......	......	......	3... $\frac{15}{16}$ ...... +
Metre .	39·3704	......	......	......	1	0	3 $\frac{5}{16}$ $\frac{1}{32}$ $\frac{1}{64}$ $\frac{1}{128}$ −
Decametre.	393·7043	......	......	1	5	1	3... $\frac{11}{16}$ ... $\frac{1}{64}$ +
Hectometre	3937·0432	......	......	19	4	2	7... $\frac{1}{32}$ $\frac{1}{64}$ ... −
Kilometre .	39370·4320	......	4	38	4	1	10 $\frac{3}{8}$ $\frac{1}{32}$ $\frac{1}{64}$ $\frac{1}{128}$ +
Myriametre	393704·3196	6	1	28	2	0	8... $\frac{5}{16}$ ... $\frac{1}{128}$ −

SOLID MEASURE.

	Cubic Metres	Cubic Inches	Cubic Feet	Cubic Yards
Millistere . .	= ·001	61·025	·03532	·00130
Centistere . .	·01	610·254	·35316	·01308
Decistere . .	·1	6102·539	3·53156	·13080
Stere[1]	1	61025·387	35·31562	1·30799
Decastere . .	10	610253·866	353·15617	13·07986
Hectostere . .	100	6102538·659	3531·56172	130·79858

WEIGHTS.

	Grammes	Av. Oz.	Av. Lbs.	Cwts.	Tons	Grains Tr.
Milligramme .	= ·001	·00004	·0000022	—	—	·015432
Centigramme .	·01	·00035	·0000221	—	—	·154323
Decigramme .	·1	·00353	·0002205	·0000020	—	1·543235
Gramme[2]. .	1	·03527	·0022046	·0000197	·000001	15·43235
Decagramme .	10	·35274	·0220462	·0001968	·000010	154·3235
Hectogramme .	100	3·5274	·2204621	·0019684	·000098	1543·235
Kilogramme	1000	35·2739	2·204621	·0196841	·000984	15432·35
Myriagramme .	10000	352·739	22·04621	·1968412	·009842	154323·5
Quintal . .	100000	3527·39	220·4621	1·968412	·098421	1543235
Millier, or Tonne	1000000	35273·9	2204·621	19·68412	·984206	15432349

DRY AND FLUID MEASURE.

	Litres	Cubic Inches	Cubic Feet	Gallons	Bushels
Millilitre .	= ·001	·06102539	—	·00022	·00003
Centilitre .	·01	·61025387	·0004	·0022	·00028
Decilitre .	·1	6·1025387	·0035	·0220	·00275
Litre[3] . .	1	61·025387	·0353	·2201	·02751
Decalitre .	10	610·25387	·3532	2·2009	·27511
Hectolitre .	100	6102·5387	3·5316	22·0091	2·75113
Kilolitre .	1000	61025·387	35·3156	220·0905	27·51132
Myrialitre .	10000	610253·87	353·1562	2200·9055	275·11318

[1] The stere is a cubic metre, and is used generally for measuring solids.

[2] The gramme is the weight in vacuo of a cubic centimetre of distilled water at the temperature of 4° of the centigrade thermometer.

[3] The litre is a cubic decimetre.

TABLES GIVING THE ENGLISH EQUIVALENTS OF 1 MILLIMETRE TO 1,000.

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
		39	1·535447	78	3·070894
1	0·039370	40	1·574817	79	3·110264
2	0·078741	41	1·614188	80	3·149635
3	0·118111	42	1·653558	81	3·189005
4	0·157482	43	1·692929	82	3·228375
5	0·196852	44	1·732299	83	3·267746
6	0·236223	45	1·771669	84	3·307116
7	0·275593	46	1·811040	85	3·346487
8	0·314963	47	1·850410	86	3·385857
9	0·354334	48	1·889781	87	3·425228
10	0·393704	49	1·929151	88	3·464598
11	0·433075	50	1·968522	89	3·503968
12	0·472445	51	2·007892	90	3·543339
13	0·511816	52	2·047262	91	3·582709
14	0·551186	53	2·086633	92	3·622080
15	0·590556	54	2·126003	93	3·661450
16	0·629927	55	2·165374	94	3·700821
17	0·669297	56	2·204744	95	3·740191
18	0·708668	57	2·244115	96	3·779561
19	0·748038	58	2·283485	97	3·818932
20	0·787409	59	2·322855	98	3·858302
21	0·826779	60	2·362226	99	3·897673
22	0·866149	61	2·401596	100	3·937043
23	0·905520	62	2·440967	101	3·976414
24	0·944890	63	2·480337	102	4·015784
25	0·984261	64	2·519708	103	4·055155
26	1·023631	65	2·559078	104	4·094525
27	1·063002	66	2·598448	105	4·133895
28	1·102372	67	2·637819	106	4·173266
29	1·141742	68	2·677189	107	4·212636
30	1·181113	69	2·716560	108	4·252007
31	1·220483	70	2·755930	109	4·291377
32	1·259854	71	2·795301	110	4·330748
33	1·299224	72	2·834671	111	4·370118
34	1·338595	73	2·874041	112	4·409488
35	1·377965	74	2·913412	113	4·448859
36	1·417335	75	2·952782	114	4·488229
37	1·456706	76	2·992153	115	4·527600
38	1·496076	77	3·031523	116	4·566970

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
117	4·606341	165	6·496121	213	8·385902
118	4·645711	166	6·535492	214	8·425272
119	4·685081	167	6·574862	215	8·464643
120	4·724452	168	6·614233	216	8·504013
121	4·763822	169	6·653603	217	8·543384
122	4·803193	170	6·692973	218	8·582754
123	4·842563	171	6·732344	219	8·622125
124	4·881934	172	6·771714	220	8·661495
125	4·921304	173	6·811085	221	8·700866
126	4·960674	174	6·850455	222	8·740236
127	5·000045	175	6·889826	223	8·779606
128	5·039415	176	6·929196	224	8·818977
129	5·078786	177	6·968567	225	8·858347
130	5·118156	178	7·007937	226	8·897718
131	5·157527	179	7·047307	227	8·937088
132	5·196897	180	7·086678	228	8·976459
133	5·236267	181	7·126048	229	9·015829
134	5·275638	182	7·165419	230	9·055199
135	5·315008	183	7·204789	231	9·094570
136	5·354379	184	7·244160	232	9·133940
137	5·393749	185	7·283530	233	9·173311
138	5·433120	186	7·322900	234	9·212681
139	5·472490	187	7·362271	235	9·252052
140	5·511861	188	7·401641	236	9·291422
141	5·551231	189	7·441012	237	9·330792
142	5·590601	190	7·480382	238	9·370163
143	5·629972	191	7·519753	239	9·409533
144	5·669342	192	7·559123	240	9·448904
145	5·708713	193	7·598493	241	9·488274
146	5·748083	194	7·637864	242	9·527645
147	5·787454	195	7·677234	243	9·567015
148	5·826824	196	7·716605	244	9·606385
149	5·866194	197	7·755975	245	9·645756
150	5·905565	198	7·795346	246	9·685126
151	5·944935	199	7·834716	247	9·724497
152	5·984306	200	7·874086	248	9·763867
153	6·023676	201	7·913457	249	9·803238
154	6·063047	202	7·952827	250	9·842608
155	6·102417	203	7·992198	251	9·881978
156	6·141787	204	8·031568	252	9·921349
157	6·181158	205	8·070939	253	9·960719
158	6·220528	206	8·110309	254	10·000090
159	6·259899	207	8·149679	255	10·039460
160	6·299269	208	8·189050	256	10·078831
161	6·338640	209	8·228420	257	10·118201
162	6·378010	210	8·267791	258	10·157571
163	6·417380	211	8·307161	259	10·196942
164	6·456751	212	8·346532	260	10·236312

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
261	10·275683	309	12·165464	357	14·055244
262	10·315053	310	12·204834	358	14·094615
263	10·354424	311	12·244204	359	14·133985
264	10·393794	312	12·283575	360	14·173356
265	10·433165	313	12·322945	361	14·212726
266	10·472535	314	12·362316	362	14·252096
267	10·511905	315	12·401686	363	14·291467
268	10·551276	316	12·441057	364	14·330837
269	10·590646	317	12·480427	365	14·370208
270	10·630017	318	12·519797	366	14·409578
271	10·669387	319	12·559168	367	14·448949
272	10·708758	320	12·598538	368	14·488319
273	10·748128	321	12·637909	369	14·527689
274	10·787498	322	12·677279	370	14·567060
275	10·826869	323	12·716650	371	14·606430
276	10·866239	324	12·756200	372	14·645801
277	10·905610	325	12·795390	373	14·685171
278	10·944980	326	12·834761	374	14·724542
279	10·984351	327	12·874131	375	14·763912
280	11·023721	328	12·913502	376	14·803282
281	11·063091	329	12·952872	377	14·842653
282	11·102462	330	12·992243	378	14·882023
283	11·141832	331	13·031613	379	14·921394
284	11·181203	332	13·070983	380	14·960764
285	11·220573	333	13·110354	381	15·000135
286	11·259944	334	13·149724	382	15·039505
287	11·299314	335	13·189095	383	15·078875
288	11·338684	336	13·228465	384	15·118246
289	11·378055	337	13·267836	385	15·157616
290	11·417425	338	13·307206	386	15·196987
291	11·456796	339	13·346576	387	15·236357
292	11·496166	340	13·385947	388	15·275728
293	11·535537	341	13·425317	389	15·315098
294	11·574907	342	13·464688	390	15·354469
295	11·614277	343	13·504058	391	15·393839
296	11·653648	344	13·543429	392	15·433209
297	11·693018	345	13·582799	393	15·472580
298	11·732389	346	13·622170	394	15·511950
299	11·771759	347	13·661540	395	15·551321
300	11·811130	348	13·700910	396	15·590691
301	11·850500	349	13·740281	397	15·630062
302	11·889871	350	13·779651	398	15·669432
303	11·929241	351	13·819022	399	15·708802
304	11·968611	352	13·858392	400	15·748173
305	12·007982	353	13·897763	401	15·787543
306	12·047352	354	13·937133	402	15·826914
307	12·086723	355	13·976503	403	15·866284
308	12·126093	356	14·015874	404	15·905655

Milli-metres	Inches and Decimals of an Inch	Milli-metres	Inches and Decimals of an Inch	Milli-metres	Inches and Decimals of an Inch
405	15·945025	453	17·834806	501	19·724586
406	15·984395	454	17·874176	502	19·763957
407	16·023766	455	17·913547	503	19·803327
408	16·063136	456	17·952917	504	19·842698
409	16·102507	457	17·992287	505	19·882068
410	16·141877	458	18·031658	506	19·921439
411	16·181248	459	18·071028	507	19·960809
412	16·220618	460	18·110399	508	20·000179
413	16·259988	461	18·149769	509	20·039550
414	16·299359	462	18·189140	510	20·078920
415	16·338729	463	18·228510	511	20·118291
416	16·378100	464	18·267880	512	20·157661
417	16·417470	465	18·307251	513	20·197032
418	16·456841	466	18·346621	514	20·236402
419	16·496211	467	18·385992	515	20·275773
420	16·535581	468	18·425362	516	20·315143
421	16·574952	469	18·464733	517	20·354513
422	16·614322	470	18·504103	518	20·393884
423	16·653693	471	18·543474	519	20·433254
424	16·693063	472	18·582844	520	20·472625
425	16·732444	473	18·622214	521	20·511995
426	16·771804	474	18·661585	522	20·551366
427	16·811175	475	18·700955	523	20·590736
428	16·850545	476	18·740326	524	20·630106
429	16·889915	477	18·779696	525	20·669477
430	16·929286	478	18·819067	526	20·708847
431	16·968656	479	18·858437	527	20·748218
432	17·008027	480	18·897807	528	20·787588
433	17·047397	481	18·937178	529	20·826959
434	17·086768	482	18·976548	530	20·866329
435	17·126138	483	19·015919	531	20·905699
436	17·165508	484	19·055289	532	20·945070
437	17·204879	485	19·094660	533	20·984440
438	17·244249	486	19·134030	534	21·023811
439	17·283620	487	19·173400	535	21·063181
440	17·322990	488	19·212771	536	21·102552
441	17·362361	489	19·252141	537	21·141922
442	17·401731	490	19·291512	538	21·181292
443	17·441101	491	19·330862	539	21·220663
444	17·480472	492	19·370253	540	21·260033
445	17·519842	493	19·409623	541	21·299404
446	17·559213	494	19·448993	542	21·338774
447	17·598583	495	19·488364	543	21·378145
448	17·637954	496	19·527734	544	21·417515
449	17·677324	497	19·567095	545	21·456885
450	17·716694	498	19·606465	546	21·496256
451	17·756065	499	19·645836	547	21·535626
452	17·795435	500	19·685216	548	21·574997

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
549	21·614367	597	23·504148	645	25·393929
550	21·653738	598	23·543518	646	25·433299
551	21·693108	599	23·582889	647	25·472670
552	21·732478	600	23·622259	648	25·512040
553	21·771849	601	23·661630	649	25·551410
554	21·811219	602	23·701000	650	25·590781
555	21·850590	603	23·740371	651	25·630151
556	21·889960	604	23·779741	652	25·669522
557	21·929331	605	23·819111	653	25·708892
558	21·968701	606	23·858482	654	25·748263
559	22·008072	607	23·897852	655	25·787633
560	22·047442	608	23·937223	656	25·827003
561	22·086812	609	23·976593	657	25·866374
562	22·126183	610	24·015964	658	25·905744
563	22·165553	611	24·055334	659	25·945115
564	22·204924	612	24·094704	660	25·984486
565	22·244294	613	24·134075	661	26·023856
566	22·283665	614	24·173445	662	26·063226
567	22·323035	615	24·212816	663	26·102596
568	22·362405	616	24·252186	664	26·141967
569	22·401776	617	24·291557	665	26·181337
570	22·441146	618	24·330927	666	26·220708
571	22·480517	619	24·370297	667	26·260078
572	22·519887	620	24·409668	668	26·299449
573	22·559928	621	24·449038	669	26·338819
574	22·598628	622	24·488409	670	26·378189
575	22·637998	623	24·527779	671	26·417560
576	22·677369	624	24·567150	672	26·456930
577	22·716739	625	24·606520	673	26·496301
578	22·756110	626	24·645890	674	26·535671
579	22·795480	627	24·685261	675	26·575042
580	22·834851	628	24·724631	676	26·614412
581	22·874221	629	24·764002	677	26·653782
582	22·913591	630	24·803372	678	26·693153
583	22·952962	631	24·842743	679	26·732523
584	22·992332	632	24·882113	680	26·771894
585	23·031703	633	24·921488	681	26·811264
586	23·071073	634	24·960854	682	26·850635
587	23·110444	635	25·000224	683	26·890005
588	23·149814	636	25·039595	684	26·929376
589	23·189184	637	25·078965	685	26·9 8746
590	23·228555	638	25·118336	686	27·008116
591	23·267925	639	25·157706	687	27·047487
592	23·307296	640	25·197077	688	27·086857
593	23·346666	641	25·236447	689	27·126228
594	23·386037	642	25·275817	690	27·165598
595	23·425407	643	25·315188	691	27·204969
596	23·464778	644	25·354558	692	27·244339

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
693	27·283709	741	29·173490	789	31·063271
694	27·323080	742	29·212861	790	31·102641
695	27·362450	743	29·252231	791	31·142012
696	27·401821	744	29 291601	792	31·181382
697	27·441191	745	29·330972	793	31·220752
698	27·480562	746	29·370342	794	31·260123
699	27·519932	747	29·409713	795	31·299493
700	27·559302	748	29·449083	796	31·338864
701	27·598673	749	29·488454	797	31·378234
702	27·638043	750	29·527824	798	31·417604
703	27·677414	751	29·567194	799	31·456975
704	27·716784	752	29·606565	800	31·496346
705	27·756155	753	29·645935	801	31·535716
706	27·795525	754	29·685306	802	31·575086
707	27·834895	755	29·724676	803	31·614457
708	27·874266	756	29·764047	804	31·653827
709	27·913636	757	29·803417	805	31·693198
710	27·953007	758	29·842787	806	31·732568
711	27·992377	759	29·882158	807	31·771938
712	28·031748	760	29·921528	808	31·811309
713	28·071118	761	29·960899	809	31·850679
714	28·110488	762	30·000269	810	31·890050
715	28·149859	763	30·039640	811	31·929420
716	28·189229	764	30·079010	812	31·968791
717	28·228600	765	30·118380	813	32·008161
718	28·267970	766	30·157751	814	32·047532
719	28·307341	767	30·197121	815	32·086902
720	28·346711	768	30·236492	816	32·126272
721	28·386081	769	30·275862	817	32·165643
722	28·425452	770	30·315233	818	32·205013
723	28·464822	771	30·354603	819	32·244384
724	28·504193	772	30·393973	820	32·283754
725	28·543563	773	30·433344	821	32·323125
726	28·582934	774	30·472714	822	32·362495
727	28·622304	775	30·512085	823	32·401866
728	28·661675	776	30·551455	824	32·441236
729	28·701045	777	30·590825	825	32·480606
730	28·740415	778	30·630196	826	32·519977
731	28·779786	779	30·669566	827	32·559347
732	28·819156	780	30·708937	828	32·598718
733	28·858527	781	30·748307	829	32·638088
734	28·897897	782	30·787678	830	32·677459
735	28·937268	783	30·827048	831	32·716829
736	28·976638	784	30·866419	832	32·756199
737	29·016008	785	30·905789	833	32·795570
738	29·055379	786	30·945159	834	32·834940
739	29·094749	787	30·984530	835	32·874311
740	29·134120	788	31·023900	836	32·913681

Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch	Millimetres	Inches and Decimals of an Inch
837	32·953052	885	34·842832	933	36·732613
838	32·992422	886	34·882203	934	36·771984
839	33·031792	887	34·921573	935	36·811354
840	33·071163	888	34·960944	936	36·850724
841	33·110533	889	35·000314	937	36·890095
842	33·149904	890	35·039684	938	36·929465
843	33·189274	891	35·079055	939	36·968836
844	33·228645	892	35·118425	940	37·008206
845	33·268015	893	35·157796	941	37·047576
846	33·307385	894	35·197166	942	37·086947
847	33·346756	895	35·236536	943	37·126317
848	33·386126	896	35·275907	944	37·165688
849	33·425497	897	35·315277	945	37·205058
850	33·464867	898	35·354648	946	37·244429
851	33·504238	899	35·394018	947	37·283799
852	33·543608	900	35·433389	948	37·323170
853	33·582979	901	35·472759	949	37·362540
854	33·622349	902	35·512130	950	37·410910
855	33·661719	903	35·551500	951	37·441281
856	33·701090	904	35·590971	952	37·480651
857	33·740460	905	35·630241	953	37·520022
858	33·779831	906	35·669611	954	37·559392
859	33·819201	907	35·708982	955	37·598765
860	33·858572	908	35·748352	956	37·638135
861	33·897942	909	35·787723	957	37·677503
862	33·937312	910	35·827093	958	37·716874
863	33·976683	911	35·866464	959	37·756244
864	34·016053	912	35·905834	960	37·795615
865	34·055424	913	35·945204	961	37·834985
866	34·094794	914	35·984575	962	37·874356
867	34·134165	915	36·023945	963	37·913726
868	34·173535	916	36·063316	964	37·953096
869	34·212905	917	36·102686	965	37·992467
870	34·252276	918	36·142057	966	38·031837
871	34·291646	919	36·181427	967	38·071208
872	34·331017	920	36·220797	968	38·110578
873	34·370387	921	36·260168	969	38·149949
874	34·409758	922	36·299538	970	38·189319
875	34·449128	923	36·338909	971	38·228689
876	34·448498	924	36·378279	972	38·268060
877	34·527869	925	36·417650	973	38·307430
878	34·567239	926	36·457020	974	38·346801
879	34·606610	927	36·496390	975	38·386171
880	34·645980	928	36·535761	976	38·425542
881	34·685351	929	36·575131	977	38·464912
882	34·724721	930	36·614502	978	38·504283
883	34·764091	931	36·653872	979	38·543653
884	34·803462	932	36·693243	980	38·583023

Milli-metres	Inches and Decimals of an Inch	Milli-metres	Inches and Decimals of an Inch	Milli-metres	Inches and Decimals of an Inch
981	38·622394	988	38·897987	995	39·173580
982	38·661764	989	38·937357	996	39·212950
983	38·701135	990	38·976728	997	39·252321
984	38·740505	991	39·016098	998	39·291691
985	38·779876	992	39·055469	999	39·331062
986	38·819246	993	39·094839	1000	39·370432
987	38·858616	994	39·134209		

TABLE GIVING THE ENGLISH EQUIVALENTS OF METRES IN INCHES AND DECIMALS OF AN INCH.

Metres	Inches and Decimals of an Inch	Metres	Inches and Decimals of an Inch	Metres	Inches and Decimals of an Inch
1	39·370432	34	1338·594687	67	2637·818941
2	78·740864	35	1377·965119	68	2677·189373
3	118·111296	36	1417·335551	69	2716·559805
4	157·481728	37	1456·705983	70	2755·930237
5	196·852160	38	1496·076415	71	2795·300669
6	236·222592	39	1535·446846	72	2834·671101
7	275·593024	40	1574·817278	73	2874·041533
8	314·963456	41	1614·187710	74	2913·411965
9	354·333888	42	1653·558142	75	2952·782397
10	393·704320	43	1692·928574	76	2992·152829
11	433·074752	44	1732·299006	77	3031·523261
12	472·445184	45	1771·669438	78	3070·893693
13	511·815616	46	1811·039870	79	3110·264125
14	551·186047	47	1850·410302	80	3149·634557
15	590·556479	48	1889·780734	81	3189·004989
16	629·926911	49	1929·151166	82	3228·375421
17	669·297343	50	1968·521598	83	3267·745853
18	708·667775	51	2007·892030	84	3307·116285
19	748·038207	52	2047·262462	85	3346·486717
20	787·408639	53	2086·632894	86	3385·857149
21	826·779071	54	2126·003326	87	3425·227581
22	866·149503	55	2165·37358	88	3464·598013
23	905·519935	56	2204·744190	89	3503·968444
24	944·890367	57	2244·114622	90	3543·338876
25	984·260799	58	2283·485054	91	3582·709308
26	1023·631231	59	2322·855486	92	3622·079740
27	1063·001663	60	2362·225918	93	3661·450172
28	1102·372095	61	2401·596350	94	3700·820604
29	1141·742527	62	2440·966782	95	3740·191036
30	1181·112959	63	2480·337214	96	3779·561468
31	1220·483391	64	2519·707645	97	3818·931900
32	1259·853823	65	2559·078077	98	3858·302332
33	1299·224255	66	2598·448509	99	3897·672764

Table giving the Equivalents in Millimetres of the Divisions of the Inch.

Divisions of the Inch				Millimetres	Divisions of the Inch				Millimetres
…	…	…	$\frac{1}{128}$	·198436	$\frac{5}{16}$	…	$\frac{1}{64}$	$\frac{1}{128}$	8·532736
…	…	$\frac{1}{64}$	…	·396871	$\frac{5}{16}$	$\frac{1}{32}$	…	…	8·731172
…	…	$\frac{1}{64}$	$\frac{1}{128}$	·595307	$\frac{5}{16}$	$\frac{1}{32}$	…	$\frac{1}{128}$	8·929007
…	$\frac{1}{32}$	…	…	·793743	$\frac{5}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	…	9·128043
…	$\frac{1}{32}$	…	$\frac{1}{128}$	·992179	$\frac{5}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	9·326479
…	$\frac{1}{32}$	$\frac{1}{64}$	…	1·190614	$\frac{3}{8}$	…	…	…	9·524915
…	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	1·389050	$\frac{3}{8}$	…	…	$\frac{1}{128}$	9·723350
$\frac{1}{16}$	…	…	…	1·587486	$\frac{3}{8}$	…	$\frac{1}{64}$	…	9·921786
$\frac{1}{16}$	…	…	$\frac{1}{128}$	1·785921	$\frac{3}{8}$	…	$\frac{1}{64}$	$\frac{1}{128}$	10·120222
$\frac{1}{16}$	…	$\frac{1}{64}$	…	1·984357	$\frac{3}{8}$	$\frac{1}{32}$	…	…	10·318657
$\frac{1}{16}$	…	$\frac{1}{64}$	$\frac{1}{128}$	2·182793	$\frac{3}{8}$	$\frac{1}{32}$	…	$\frac{1}{128}$	10·517093
$\frac{1}{16}$	$\frac{1}{32}$	…	…	2·385129	$\frac{3}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	…	10·715529
$\frac{1}{16}$	$\frac{1}{32}$	…	$\frac{1}{128}$	2·579664	$\frac{3}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	10·913965
$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	…	2·778100	$\frac{7}{16}$	…	…	…	11·112400
$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	2·976536	$\frac{7}{16}$	…	…	$\frac{1}{128}$	11·310836
$\frac{1}{8}$	…	…	…	3·174972	$\frac{7}{16}$	…	$\frac{1}{64}$	…	11·509272
$\frac{1}{8}$	…	…	$\frac{1}{128}$	3·373407	$\frac{7}{16}$	…	$\frac{1}{64}$	$\frac{1}{128}$	11·707707
$\frac{1}{8}$	…	$\frac{1}{64}$	…	3·571843	$\frac{7}{16}$	$\frac{1}{32}$	…	…	11·906143
$\frac{1}{8}$	…	$\frac{1}{64}$	$\frac{1}{128}$	3·770279	$\frac{7}{16}$	$\frac{1}{32}$	…	$\frac{1}{128}$	12·104579
$\frac{1}{8}$	$\frac{1}{32}$	…	…	3·968714	$\frac{7}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	…	12·303015
$\frac{1}{8}$	$\frac{1}{32}$	…	$\frac{1}{128}$	4·167150	$\frac{7}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	12·501450
$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	…	4·365586	$\frac{1}{2}$	…	…	…	12·699886
$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	4·564022	$\frac{1}{2}$	…	…	$\frac{1}{128}$	12·898322
$\frac{3}{16}$	…	…	…	4·762457	$\frac{1}{2}$	…	$\frac{1}{64}$	…	13·096757
$\frac{3}{16}$	…	…	$\frac{1}{128}$	4·960893	$\frac{1}{2}$	…	$\frac{1}{64}$	$\frac{1}{128}$	13·295193
$\frac{3}{16}$	…	$\frac{1}{64}$	…	5·159329	$\frac{1}{2}$	$\frac{1}{32}$	…	…	13·493629
$\frac{3}{16}$	…	$\frac{1}{64}$	$\frac{1}{128}$	5·357764	$\frac{1}{2}$	$\frac{1}{32}$	…	$\frac{1}{128}$	13·692065
$\frac{3}{16}$	$\frac{1}{32}$	…	…	5·556200	$\frac{1}{2}$	$\frac{1}{32}$	$\frac{1}{64}$	…	13·890500
$\frac{3}{16}$	$\frac{1}{32}$	…	$\frac{1}{128}$	5·754636	$\frac{1}{2}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	14·088936
$\frac{3}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	…	5·953072	$\frac{9}{16}$	…	…	…	14·287372
$\frac{3}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	6·151508	$\frac{9}{16}$	…	…	$\frac{1}{128}$	14·485808
$\frac{1}{4}$	…	…	…	6·349943	$\frac{9}{16}$	…	$\frac{1}{64}$	…	14·684243
$\frac{1}{4}$	…	…	$\frac{1}{128}$	6·548379	$\frac{9}{16}$	…	$\frac{1}{64}$	$\frac{1}{128}$	14·882679
$\frac{1}{4}$	…	$\frac{1}{64}$	…	6·746814	$\frac{9}{16}$	$\frac{1}{32}$	…	…	15·081115
$\frac{1}{4}$	…	$\frac{1}{64}$	$\frac{1}{128}$	6·945250	$\frac{9}{16}$	$\frac{1}{32}$	…	$\frac{1}{128}$	15·279550
$\frac{1}{4}$	$\frac{1}{32}$	…	…	7·143686	$\frac{9}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	…	15·477986
$\frac{1}{4}$	$\frac{1}{32}$	…	$\frac{1}{128}$	7·342122	$\frac{9}{16}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	15·676422
$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{64}$	…	7·540557	$\frac{5}{8}$	…	…	…	15·874858
$\frac{1}{4}$	$\frac{1}{32}$	$\frac{1}{64}$	$\frac{1}{128}$	7·738993	$\frac{5}{8}$	…	…	$\frac{1}{128}$	16·073293
$\frac{5}{16}$	…	…	…	7·937429	$\frac{5}{8}$	…	$\frac{1}{64}$	…	16·271729
$\frac{5}{16}$	…	…	$\frac{1}{128}$	8·135865	$\frac{5}{8}$	…	$\frac{1}{64}$	$\frac{1}{128}$	16·470165
$\frac{5}{16}$	…	$\frac{1}{64}$	…	8·334300	$\frac{5}{8}$	$\frac{1}{32}$	…	…	16·668600

Divisions of the Inch				Millimetres	Divisions of the Inch				Millimetres
5/8	1/32	...	1/128	16·867036	13/16	...	1/64	1/128	21·232622
5/8	1/32	1/64	...	17·065472	13/16	1/32	...	...	21·431058
5/8	1/32	1/64	1/128	17·263908	13/16	1/32	...	1/128	21·629493
11/16	...	...	...	17·462343	13/16	1/32	1/64	...	21·827929
11/16	...	...	1/128	17·660779	13/16	1/32	1/64	1/128	22·026365
11/16	...	1/64	...	17·859215	7/8	...	...	...	22·224801
11/16	...	1/64	1/128	18·057650	7/8	...	...	1/128	22·423236
11/16	1/32	...	...	18·256086	7/8	...	1/64	...	22·621672
11/16	1/32	...	1/128	18·454522	7/8	...	1/64	1/128	22·820108
11/16	1/32	1/64	...	18·652958	7/8	1/32	...	...	23·018543
11/16	1/32	1/64	1/128	18·851393	7/8	1/32	...	1/128	23·216979
3/4	...	...	...	19·049829	7/8	1/32	1/64	...	23·415415
3/4	...	...	1/128	19·248265	7/8	1/32	1/64	1/128	23·613851
3/4	...	1/64	...	19·446701	15/16	...	...	...	23·812286
3/4	...	1/64	1/128	19·645136	15/16	...	...	1/128	24·010722
3/4	1/32	...	...	19·843572	15/16	...	1/64	...	24·209158
3/4	1/32	...	1/128	20·042008	15/16	...	1/64	1/128	24·407594
3/4	1/32	1/64	...	20·240443	15/16	1/32	...	...	24·606029
3/4	1/32	1/64	1/128	20·438879	15/16	1/32	...	1/128	24·804465
13/16	...	...	...	20·637315	15/16	1/32	1/64	...	25·002901
13/16	...	...	1/128	20·835751	15/16	1/32	1/64	1/128	25·201336
13/16	...	1/64	...	21·034186	1	...	...	...	25·399772

Table giving the Equivalents in Millimetres of the Divisions of the Foot.

In.	Millimetres	In.	Millimetres	In.	Millimetres	In.	Millimetres
1	25·39977	10	253·99772	19	482·59567	28	711·19362
2	50·79954	11	279·39749	20	507·99544	29	736·59339
3	76·19932	12	304·79727	21	533·39521	30	761·99316
4	101·59909	13	330·19704	22	558·79499	31	787·39294
5	126·99886	14	355·59681	23	584·19476	32	812·79271
6	152·39863	15	380·99658	24	609·59453	33	838·19248
7	177·79840	16	406·39635	25	634·99430	34	863·59225
8	203·19818	17	431·79613	26	660·39408	35	888·99202
9	228·59795	18	457·19590	27	685·78385	36	914·39180

Table giving the Equivalents of Lineal Feet in Metres.

Ft.	Metres	Ft.	Metres	Ft.	Metres	Ft.	Metres
1	·3047973	6	1·8287840	11	3·3527706	16	4·8767573
2	·6095947	7	2·1335813	12	3·6755680	17	5·1815546
3	·9143920	8	2·4383786	13	3·9623653	18	5·4863519
4	1·2191893	9	2·7431760	14	4·2671626	19	5·7911493
5	1·5239867	10	3·0479733	15	4·5719600	20	6·0959466

Table giving the Equivalents of Avoir. Oz. in French Kilograms.

Oz.	Kilograms	Oz.	Kilograms	Oz.	Kilograms	Oz.	Kilograms
1	·028349541	5	·141747704	9	·255145867	13	·368544030
2	·056699082	6	·170097245	10	·283495408	14	·396893571
3	·085048622	7	·198446785	11	·311844948	15	·425243112
4	·113398163	8	·226796326	12	·340194489	16	·453592652

Table giving the Equivalents of Avoir. Lbs. in French Kilograms.

Lbs.	Kilograms	Lbs.	Kilograms	Lbs.	Kilograms	Lbs.	Kilograms
1	·45359265	8	3·62874122	15	6·80388978	22	9·97903835
2	·90718530	9	4·08233387	16	7·25748243	23	10·43263100
3	1·36077796	10	4·53592652	17	7·71107509	24	10·88622365
4	1·81437061	11	4·98951917	18	8·16466774	25	11·33981631
5	2·26796326	12	5·44311183	19	8·61826039	26	11·79340896
6	2·72155591	13	5·89670448	20	9·07185305	27	12·24700161
7	3·17514857	14	6·35029713	21	9·52544570	28	12·70059426

Table giving the Equivalents of Quarters in French Kilograms.

Qr.	Kilograms	Qrs.	Kilograms	Qrs.	Kilograms	Qrs.	Kilograms
1	12·70059426	2	25·40118853	3	38·10178279	4	50·80237705

Table giving the Equivalents of Cwts. in French Kilograms.

Cwt	Kilograms	Cwt	Kilograms	Cwt	Kilograms	Cwt	Kilograms
1	50·80237705	6	304·81426231	11	558·82614757	16	812·83803283
2	101·60475410	7	355·61663936	12	609·62852462	17	863·64040988
3	152·40713116	8	406·41901642	13	660·43090168	18	914·44278694
4	203·20950821	9	457·22139347	14	711·23327873	19	965·24516399
5	254·01188526	10	508·02377052	15	762·03565578	20	1016·0475411

Table giving the Equivalents of Tons in French Kilograms.

Tons	Kilograms	Tons	Kilograms	Tons	Kilograms	Tons	Kilograms
1	1016·04754	20	20320·9508	300	304814·262	1300	1320861·80
2	2032·09508	30	30481·4262	400	406419·016	1400	1422466·56
3	3048·14262	40	40641·9016	500	508023·771	1500	1524071·31
4	4064·19016	50	50802·3771	600	609628·525	1600	1625676·07
5	5080·23771	60	60962·8525	700	711233·279	1700	1727280·82
6	6096·28525	70	71123·3279	800	812838·033	1800	1828885·57
7	7112·33279	80	81283·8033	900	914442·787	1900	1930490·33
8	8128·38033	90	91444·2787	1000	1016047·54	2000	2032095·08
9	9144·42787	100	101604·754	1100	1117652·30	3000	3048142·62
10	10160·4754	200	203209·508	1200	1219257·05	4000	4064190·16

TABLE GIVING THE EQUIVALENTS OF KILOGRAMS IN AVOIRDUPOIS POUNDS AND TONS.

Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton
1	2·20462	·00098421	26	57·32015	·02558935	51	112·43568	·05019450	76	167·55122	·07479965
2	4·40924	·00196841	27	59·52477	·02657356	52	114·64031	·05117871	77	169·75584	·07578386
3	6·61386	·00295262	28	61·72940	·02755777	53	116·84493	·05216291	78	171·96046	·07676806
4	8·81849	·00393682	29	63·93402	·02854197	54	119·04955	·05314712	79	174·16508	·07775227
5	11·02311	·00492103	30	66·13864	·02952618	55	121·25417	·05413133	80	176·36970	·07873647
6	13·22773	·00590524	31	68·34326	·03051038	56	123·45879	·05511553	81	178·57432	·07972068
7	15·43235	·00688944	32	70·54788	·03149459	57	125·66341	·05609974	82	180·77894	·08070489
8	17·63697	·00787365	33	72·75250	·03247880	58	127·86803	·05708394	83	182·98356	·08168909
9	19·84159	·00885785	34	74·95712	·03346300	59	130·07265	·05806815	84	185·18819	·08267330
10	22·04621	·00984206	35	77·16174	·03444721	60	132·27728	·05905235	85	187·39281	·08365750
11	24·25083	·01082627	36	79·36637	·03543141	61	134·48190	·06003656	86	189·59743	·08464171
12	26·45555	·01181047	37	81·57099	·03641562	62	136·68652	·06102077	87	191·80205	·08562591
13	28·66008	·01279468	38	83·77561	·03739982	63	138·89114	·06200497	88	194·00667	·08661012
14	30·86470	·01377888	39	85·98023	·03838403	64	141·09576	·06298918	89	196·21129	·08759433
15	33·06932	·01476309	40	88·18485	·03936824	65	143·30038	·06397338	90	198·41591	·08857853
16	35·27394	·01574729	41	90·38947	·04035244	66	145·50500	·06495759	91	200·62053	·08956274
17	37·47856	·01673150	42	92·59409	·04133665	67	147·70962	·06594180	92	202·82516	·09054694
18	39·68318	·01771571	43	94·79871	·04232085	68	149·91425	·06692600	93	205·02978	·09153115
19	41·88780	·01869991	44	97·00334	·04330506	69	152·11887	·06791021	94	207·23440	·09251536
20	44·09243	·01968412	45	99·20796	·04428927	70	154·32349	·06889441	95	209·43902	·09349956
21	46·29705	·02066832	46	101·41258	·04527347	71	156·52811	·06987862	96	211·64364	·09448377
22	48·50167	·02165253	47	103·61720	·04625768	72	158·73273	·07086283	97	213·84826	·09546797
23	50·70629	·02263674	48	105·82182	·04724188	73	160·93735	·07184703	98	216·05288	·09645218
24	52·91091	·02362094	49	108·02644	·04822609	74	163·14197	·07283124	99	218·25750	·09743639
25	55·11553	·02460515	50	110·23106	·04921030	75	165·34659	·07381544	100	220·46213	·09842059

TABLE GIVING THE EQUIVALENTS OF KILOGRAMS IN AVOIRDUPOIS POUNDS AND TONS (concluded).

Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton	Kilos.	Avoir. Lbs.	Ton
101	222·66675	·09940480	126	277·78228	·12400995	151	332·89781	·14861509	176	388·01334	·17322024
102	224·87137	·10038900	127	279·98690	·12499415	152	335·10243	·14959930	177	390·21796	·17420445
103	227·07599	·10137321	128	282·29152	·12597836	153	337·30705	·15058351	178	392·42258	·17518865
104	229·28061	·10235742	129	284·49614	·12696256	154	339·51167	·15156771	179	394·62720	·17617286
105	231·48523	·10334162	130	286·60076	·12794677	155	341·71629	·15255192	180	396·83183	·17715706
106	233·68985	·10432583	131	288·80538	·12893097	156	343·92092	·15353612	181	399·03645	·17814127
107	235·89447	·10531003	132	291·01001	·12991518	157	346·12554	·15452033	182	401·24107	·17912548
108	238·09910	·10629424	133	293·21463	·13089939	158	348·33016	·15550453	183	403·44569	·18010968
109	240·30372	·10727844	134	295·41925	·13188359	159	350·53478	·15648874	184	405·65031	·18109389
110	242·50834	·10826265	135	297·62387	·13286780	160	352·73940	·15747295	185	407·85493	·18207809
111	244·71296	·10924686	136	299·82849	·13385200	161	354·94402	·15845715	186	410·05955	·18306230
112	246·91758	·11023106	137	302·03311	·13483621	162	357·14864	·15944136	187	412·26417	·18404651
113	249·12220	·11121527	138	304·23773	·13582042	163	359·35326	·16042556	188	414·46880	·18503071
114	251·32682	·11219947	139	306·44235	·13680462	164	361·55789	·16140977	189	416·67342	·18601492
115	253·53144	·11318368	140	308·64698	·13778883	165	363·76251	·16239398	190	418·87804	·18699912
116	255·73607	·11416789	141	310·85160	·13877303	166	365·96713	·16337818	191	421·08266	·18798333
117	257·94069	·11515209	142	313·05622	·13975724	167	368·17175	·16436239	192	423·28728	·18896754
118	260·14531	·11613630	143	315·26084	·14074145	168	370·37637	·16534659	193	425·49190	·18995174
119	262·34993	·11712050	144	317·46546	·14172565	169	372·58099	·16633080	194	427·69652	·19093595
120	264·55455	·11810471	145	319·67008	·14270986	170	374·78561	·16731501	195	429·90114	·19192015
121	266·75917	·11908892	146	321·87470	·14369406	171	376·99023	·16829921	196	432·10577	·19290436
122	268·96379	·12007312	147	324·07932	·14467827	172	379·19486	·16928342	197	434·31039	·19388857
123	271·16841	·12105733	148	326·28395	·14566248	173	381·39948	·17026762	198	436·51501	·19487277
124	273·37304	·12204153	149	328·48857	·14664668	174	383·60410	·17125183	199	438·71963	·19585698
125	275·57766	·12302574	150	330·69319	·14763089	175	385·80872	·17223604	200	440·92425	·19684118

Table of the Decimal Equivalents of Parts of a Ton.

Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton
1	·000446	370	·165179	820	·366071	1270	·566964
2	·000893	380	·169643	830	·370536	1280	·571429
3	·001339	390	·174107	840	·375000	1290	·575893
4	·001786	400	·178571	850	·379464	1300	·580357
5	·002232	410	·183036	860	·383929	1310	·584821
6	·002679	420	·187500	870	·388393	1320	·589286
7	·003125	430	·191964	880	·392857	1330	·593750
8	·003571	440	·196429	890	·397321	1340	·598214
9	·004018	450	·200893	900	·401786	1350	·602679
10	·004464	460	·205357	910	·406250	1360	·607143
20	·008929	470	·209821	920	·410714	1370	·611607
30	·013393	480	·214286	930	·415179	1380	·616071
40	·017851	490	·218750	940	·419643	1390	·620536
50	·022321	500	·223214	950	·424107	1400	·625000
60	·026786	510	·227679	960	·428571	1410	·629464
70	·031250	520	·232143	970	·433036	1420	·633929
80	·035714	530	·236607	980	·437500	1430	·638393
90	·040179	540	·241071	990	·441964	1440	·642857
100	·044643	550	·245536	1000	·446429	1450	·647321
110	·049107	560	·250000	1010	·450893	1460	·651786
120	·053571	570	·254464	1020	·455357	1470	·656250
130	·058036	580	·258929	1030	·459821	1480	·660714
140	·062500	590	·263393	1040	·464286	1490	·665179
150	·066964	600	·267857	1050	·468750	1500	·669643
160	·071429	610	·272321	1060	·473214	1510	·674107
170	·075893	620	·276786	1070	·477679	1520	·678571
180	·080357	630	·281250	1080	·482143	1530	·683036
190	·084821	640	·285714	1090	·486607	1540	·687500
200	·089286	650	·290179	1100	·491071	1550	·691964
210	·093750	660	·294643	1110	·495536	1560	·696429
220	·098214	670	·299107	1120	·500000	1570	·700893
230	·102679	680	·303571	1130	·504464	1580	·705357
240	·107143	690	·308036	1140	·508929	1590	·709821
250	·111607	700	·312500	1150	·513393	1600	·714286
260	·116071	710	·316964	1160	·517857	1610	·718750
270	·120536	720	·321429	1170	·522321	1620	·723214
280	·125000	730	·325893	1180	·526786	1630	·727679
290	·129464	740	·330357	1190	·531250	1640	·732143
300	·133929	750	·334821	1200	·535714	1650	·736607
310	·138393	760	·339286	1210	·540179	1660	·741071
320	·142857	770	·343750	1220	·544643	1670	·745536
330	·147321	780	·348214	1230	·549107	1680	·750000
340	·151786	790	·352679	1240	·553571	1690	·754464
350	·156250	800	·357143	1250	·558036	1700	·758929
360	·160714	810	·361607	1260	·562500	1710	·763393

TABLE OF THE DECIMAL EQUIVALENTS OF PARTS OF A TON (concluded).

Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton	Lbs.	Decimals of a Ton
1720	·767857	1850	·825893	1980	·883929	2110	·941964
1730	·772321	1860	·830357	1990	·888393	2120	·946429
1740	·776786	1870	·834821	2000	·892857	2130	·950893
1750	·781250	1880	·839286	2010	·897321	2140	·955357
1760	·785714	1890	·843750	2020	·901786	2150	·959821
1770	·790179	1900	·848214	2030	·906250	2160	·964286
1780	·794643	1910	·852679	2040	·910714	2170	·968750
1790	·799107	1920	·857143	2050	·915179	2180	·973214
1800	·803571	1930	·861607	2060	·919643	2190	·977679
1810	·808036	1940	·866071	2070	·924107	2200	·982143
1820	·812500	1950	·870536	2080	·928571	2210	·986607
1830	·816964	1960	·875000	2090	·933036	2220	·991071
1840	·821429	1970	·879464	2100	·937500	2230	·995536

2240 lbs. = 1 ton

Ozs.	Decimals of a Lb.	Ozs.	Decimals of a Lb.	Ozs.	Decimals of a Lb.	Ozs.	Decimals of a Lb.
¼	·015625	4¼	·265625	8¼	·515625	12¼	·765625
½	·031250	4½	·281250	8½	·531250	12½	·781250
¾	·046875	4¾	·296875	8¾	·546875	12¾	·796875
1	·062500	5	·312500	9	·562500	13	·812500
1¼	·078125	5¼	·328125	9¼	·578125	13¼	·828125
1½	·093750	5½	·343750	9½	·593750	13½	·843750
1¾	·109375	5¾	·359375	9¾	·609375	13¾	·859375
2	·125000	6	·375000	10	·625000	14	·875000
2¼	·140625	6¼	·390625	10¼	·640625	14¼	·890625
2½	·156250	6½	·406250	10½	·656250	14½	·906250
2¾	·171875	6¾	·421875	10¾	·671875	14¾	·921875
3	·187500	7	·437500	11	·687500	15	·937500
3¼	·203125	7¼	·453125	11¼	·703125	15¼	·953125
3½	·218750	7½	·468750	11½	·718750	15½	·968750
3¾	·234375	7¾	·484375	11¾	·734375	15¾	·984375
4	·250000	8	·500000	12	·750000	16	1·000000

Qr.	Decimals of a Ton	Qrs.	Decimals of a Ton	Qrs.	Decimals of a Ton	Qrs.	Decimals of a Ton
1	·012500	2	·025000	3	·037500	4	·050000

Cwts.	Decimals of a Ton	Cwts.	Decimals of a Ton	Cwts.	Decimals of a Ton	Cwts.	Decimals of a Ton	Cwts	Decimals of a Ton
1	·050	5	·250	9	·450	13	·650	17	·850
2	·100	6	·300	10	·500	14	·700	18	·900
3	·150	7	·350	11	·550	15	·750	19	·950
4	·200	8	·400	12	·600	16	·800	20	1·000

Table of the Decimal Equivalents of the Divisions of the Foot.

In.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	In.
0	·0000	·0052	·0104	·0156	·0208	·0260	·0313	·0365	·0417	·0469	·0521	·0573	·0625	·0677	·0729	·0781	0
1	·0833	·0885	·0937	·0990	·1042	·1094	·1146	·1198	·1250	·1302	·1354	·1406	·1458	·1510	·1563	·1615	1
2	·1667	·1719	·1771	·1823	·1875	·1927	·1979	·2031	·2083	·2135	·2188	·2240	·2292	·2344	·2396	·2448	2
3	·2500	·2552	·2604	·2656	·2708	·2760	·2813	·2865	·2917	·2969	·3021	·3073	·3125	·3177	·3229	·3281	3
4	·3333	·3385	·3437	·3490	·3542	·3594	·3646	·3698	·3750	·3802	·3854	·3906	·3958	·4010	·4063	·4115	4
5	·4167	·4219	·4271	·4323	·4375	·4427	·4479	·4531	·4583	·4635	·4688	·4740	·4792	·4844	·4896	·4948	5
6	·5000	·5052	·5104	·5156	·5208	·5260	·5313	·5365	·5417	·5469	·5521	·5573	·5625	·5677	·5729	·5781	6
7	·5833	·5885	·5937	·5990	·6042	·6094	·6146	·6198	·6250	·6302	·6354	·6406	·6458	·6510	·6563	·6615	7
8	·6667	·6719	·6771	·6823	·6875	·6927	·6979	·7031	·7083	·7135	·7187	·7240	·7292	·7344	·7396	·7448	8
9	·7500	·7552	·7604	·7656	·7708	·7760	·7813	·7865	·7917	·7969	·8021	·8073	·8125	·8177	·8229	·8281	9
10	·8333	·8385	·8437	·8490	·8542	·8594	·8646	·8698	·8750	·8802	·8854	·8906	·8958	·9010	·9063	·9115	10
11	·9167	·9219	·9271	·9323	·9375	·9427	·9479	·9531	·9583	·9635	·9688	·9740	·9792	·9844	·9896	·9948	11
In.	0	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	In.

Table of the Decimal Equivalents of the Divisions of the Yard.

Feet	0	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{3}{12}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{9}{12}$	$\frac{5}{6}$	$\frac{11}{12}$	Feet
0	·0000	·0278	·0556	·0833	·1111	·1389	·1667	·1944	·2222	·2500	·2778	·3056	0
1	·3333	·3611	·3889	·4167	·4444	·4722	·5000	·5278	·5556	·5833	·6111	·6389	1
2	·6667	·6944	·7222	·7500	·7778	·8056	·8333	·8611	·8889	·9167	·9444	·9722	2
Feet	0	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{3}{12}$	$\frac{1}{3}$	$\frac{5}{12}$	$\frac{1}{2}$	$\frac{7}{12}$	$\frac{2}{3}$	$\frac{9}{12}$	$\frac{5}{6}$	$\frac{11}{12}$	Feet

TABLE OF THE FRACTIONAL PARTS OF THE INCH, WITH THEIR CORRESPONDING DECIMALS.

Decimals	Fractions	Decimals	Fractions	Decimals	Fractions
		·3359375	5/16 ... 1/64 1/128	·6718750	5/8 1/32 1/64 ...
·0078125	... ... 1/128	·3437500	5/16 1/32	·6796875	5/8 1/32 1/64 1/128
·0156250	... ... 1/64 ...	·3515625	5/16 1/32 ... 1/128	·6875000	11/16 ... ...
·0234375	... ... 1/64 1/128	·3593750	5/16 1/32 1/64 ...	·6953125	11/16 ... ... 1/128
·0312500	... 1/32	·3671875	5/16 1/32 1/64 1/128	·7031250	11/16 ... 1/64 ...
·0390625	... 1/32 ... 1/128	·3750000	3/8	·7109375	11/16 ... 1/64 1/128
·0468750	... 1/32 1/64 ...	·3828125	3/8 ... ... 1/128	·7187500	11/16 1/32 ... ...
·0546875	... 1/32 1/64 1/128	·3906250	3/8 ... 1/64 ...	·7265625	11/16 1/32 ... 1/128
·0625000	1/16	·3984375	3/8 ... 1/64 1/128	·7343750	11/16 1/32 1/64 ...
·0703125	1/16 ... ... 1/128	·4062500	3/8 1/32	·7421875	11/16 1/32 1/64 1/128
·0781250	1/16 ... 1/64 ...	·4140625	3/8 1/32 ... 1/128	·7500000	3/4 ... ...
·0859375	1/16 ... 1/64 1/128	·4218750	3/8 1/32 1/64 ...	·7578125	3/4 ... ... 1/128
·0937500	1/16 1/32	·4296875	3/8 1/32 1/64 1/128	·7656250	3/4 ... 1/64 ...
·1015625	1/16 1/32 ... 1/128	·4375000	7/16	·7734375	3/4 ... 1/64 1/128
·1093750	1/16 1/32 1/64 ...	·4453125	7/16 ... ... 1/128	·7812500	3/4 1/32 ... ...
·1171875	1/16 1/32 1/64 1/128	·4531250	7/16 ... 1/64 ...	·7890625	3/4 1/32 ... 1/128
·1250000	1/8	·4609375	7/16 ... 1/64 1/128	·7968750	3/4 1/32 1/64 ...
·1328125	1/8 ... ... 1/128	·4687500	7/16 1/32	·8046875	3/4 1/32 1/64 1/128
·1406250	1/8 ... 1/64 ...	·4765625	7/16 1/32 ... 1/128	·8125000	13/16 ... ...
·1484375	1/8 ... 1/64 1/128	·4843750	7/16 1/32 1/64 ...	·8203125	13/16 ... ... 1/128
·1562500	1/8 1/32	·4921875	7/16 1/32 1/64 1/128	·8281250	13/16 ... 1/64 ...
·1640625	1/8 1/32 ... 1/128	·5000000	1/2	·8359375	13/16 ... 1/64 1/128
·1718750	1/8 1/32 1/64 ...	·5078125	1/2 ... ... 1/128	·8437500	13/16 1/32 ... ...
·1796875	1/8 1/32 1/64 1/128	·5156250	1/2 ... 1/64 ...	·8515625	13/16 1/32 ... 1/128
·1875000	3/16	·5234375	1/2 ... 1/64 1/128	·8593750	13/16 1/32 1/64 ...
·1953125	3/16 ... ... 1/128	·5312500	1/2 1/32	·8671875	13/16 1/32 1/64 1/128
·2031250	3/16 ... 1/64 ...	·5390625	1/2 1/32 ... 1/128	·8750000	7/8 ... ...
·2109375	3/16 ... 1/64 1/128	·5468750	1/2 1/32 1/64 ...	·8828125	7/8 ... ... 1/128
·2187500	3/16 1/32	·5546875	1/2 1/32 1/64 1/128	·8906250	7/8 ... 1/64 ...
·2265625	3/16 1/32 ... 1/128	·5625000	9/16	·8984375	7/8 ... 1/64 1/128
·2343750	3/16 1/32 1/64 ...	·5703125	9/16 ... ... 1/128	·9062500	7/8 1/32 ... ...
·2421875	3/16 1/32 1/64 1/128	·5781250	9/16 ... 1/64 ...	·9140625	7/8 1/32 ... 1/128
·2500000	1/4	·5859375	9/16 ... 1/64 1/128	·9218750	7/8 1/32 1/64 ...
·2578125	1/4 ... ... 1/128	·5937500	9/16 1/32	·9296875	7/8 1/32 1/64 1/128
·2656250	1/4 ... 1/64 ...	·6015625	9/16 1/32 ... 1/128	·9375000	15/16 ... ...
·2734375	1/4 ... 1/64 1/128	·6093750	9/16 1/32 1/64 ...	·9453125	15/16 ... ... 1/128
·2812500	1/4 1/32	·6171875	9/16 1/32 1/64 1/128	·9531250	15/16 ... 1/64 ...
·2890625	1/4 1/32 ... 1/128	·6250000	5/8	·9609375	15/16 ... 1/64 1/128
·2968750	1/4 1/32 1/64 ...	·6328125	5/8 ... ... 1/128	·9687500	15/16 1/32 ... ...
·3046875	1/4 1/32 1/64 1/128	·6406250	5/8 ... 1/64 ...	·9765625	15/16 1/32 ... 1/128
·3125000	5/16	·6484375	5/8 ... 1/64 1/128	·9843750	15/16 1/32 1/64 ...
·3203125	5/16 ... ... 1/128	·6562500	5/8 1/32	·9921875	15/16 1/32 1/64 1/128
·3281250	5/16 ... 1/64 ...	·6640625	5/8 1/32 ... 1/128	1·0000000	1 ... ...

TABLE OF FOREIGN MONEY, WEIGHTS, AND MEASURES, WITH THEIR ENGLISH VALUE.

Countries	MONEY					
	Gold Coins	Value	Silver Coins	Value	Silver Coins	Value
		£ s. d.		s. d.		s. d.
Austria	8 florins	15 10	2 florins	3 11½	¼ florin	5¾
Bombay	Mohur	1 9 2	Rupee	1 10½	¼ rupee	5½
China	—	—	Tael	6 8	Mace	7
Denmark	20 krondaler	1 1 11½	4 krondaler	4 5⅓	Krondaler	1 1⅓
France[1]	20 francs	15 10	5 francs	3 11	Franc	9½
Germany	20 reichs-mark	1 0 0	5 reichs-mark	5 0	20 pfennige	2½
Greece	20 drachma	15 10	5 drachma	3 10	Drachma	9½
Holland	Ryder	1 5 1	Guilder	1 8	25 cents	5
Madras	Mohur	1 9 2	Rupee	1 10½	¼ rupee	5½
Portugal	5 milreas	1 3 4	500 reas	2 2	50 reas	2⅝
Russia	10 roubles	1 12 2½	Rouble	3 1½	25 copecs	9⅜
Spain	20 pesetas	15 10	5 pesetas	3 11½	Peseta	9½
Sweden	20 krondaler	1 1 11½	4 krondaler	4 5⅓	Daler	8¾

Countries	LENGTH					
	Measure	Length	Measure	Length	Measure	Length
		Inches		Feet		Miles
Austria	Fuss	12·445	Klafter	6·2226	Meile	4·7142
Bombay	Hath	18	Guz	2·25	—	—
China	Chik	14·1	Yan	117·5	Li	·3458
Denmark	Fod	12·357	Aln	2·0595	Mill	4·6807
France	Mètre	39·3704	Décamètre	32·809	Myriamètre	6·2138
Germany	Fuss	12·357	Ruthe	12·357	Postmeile	4·6807
Greece	Attic foot	12·10	Stadium	600	—	—
Holland	Palm	3·93704	Elle	3·2809	Mijle	·6214
Madras	Covid	18·6	—	—	—	—
Portugal	Palmo	8·656	Vara	3·6067	Mil	1·2786
Russia	Archine	28	Sachine	7	Verst	·6629
Spain	Pie	11·128	Vara	2·782	Legua	4·2152
Sweden	Fot	11·6904	Famn	5 8452	Mil	6·6423

Countries	LIQUID CAPACITY					
	Measures	Gallons	Measures	Gallons	Measures	Gallons
Austria	Kanne	·1557	Viertel	3·1143	Eimer	12·4572
Bombay	Adoulie	1·515	Para	24·24	Candy	193·92
China	Shingtsong	·12	Tau	1·2	Hwŭh	12
Denmark	Pott	·2126	Viertel	1·7008	Anker	8·2914
France	Litre	·2201	Décalitre	2·2009	Hectolitre	22·0097
Germany	Quartier	·252	Anker	7·559	Eimer	15·118
Greece	—	—	Metretes	8·488	—	—
Holland	Kan	·2201	—	—	Vat	22·0097
Madras	Puddy	·338	Marcal	2·704	Parah	13·52
Portugal	Canada	·3034	Pote	1·8202	Almŭde	3·6405
Russia	Vedro	2·7049	Anker	8 1147	Sarokowaja	324·588
Spain	Quartillo	·1105	Azumbre	·4422	Arroba	3·5380
Sweden	Stop	·2878	Kanna	·5756	Tunna	27·6288

[1] France, Italy, Belgium, and Switzerland have perfect reciprocity in their urrency.

TABLE OF FOREIGN MONEY, WEIGHTS, AND MEASURES, WITH THEIR ENGLISH VALUE (concluded).

Countries	DRY CAPACITY					
	Measure	Contents	Measure	Contents	Measure	Contents
		Bushels		Bushels		Quarters
Austria	Viertel	·4230	Metze	1·6918	Muth	6·3442
Bombay	Adoulie	·1893	Parah	3·03	Candy	3·3
China	Shingtsong	·02	Tau	·2	Hwŭh	·25
Denmark	Fjerding	·9567	Tonne	3·8268	Last	10·5235
France	Décalitre	·2751	Hectolitre	2·7511	Kilolitre	3·564
Germany	Viertel	·3780	Scheffel	1·5121	Wispel	3·4022
Greece	Bachel	·753	Kila	·9152	Staro	·2824
Holland	Schepel	·2751	Mudde	2·7511	Last	10·317
Madras	Puddy	·0423	Parah	1·69	Garce	16·9
Portugal	Alqueire	·372	Fanga	1·4878	Moio	2·79
Russia	Pajak	1·4426	Osmin	2·8852	Tschetwert	·7213
Spain	Almude	·1292	Fanega	1·5503	Cahiz	2·3254
Sweden	Kanna	·0720	Spann	2·015	Tunna	·50375

Countries	WEIGHT					
	Name	Weight	Name	Weight	Name	Weight
		Lbs.		Lbs.		Tons
Austria	Pfund	1·2352	Centner	12·352	—	—
Bombay	Seer	·7	Maund	28	Candy	·25
China	Tael	·0833	Catty	1·333	Pecul	·0595
Denmark	Mark	·5514	Pund	1·1029	Skippund	·1575
France	Kilogramme	2·2046	Quintal	220·46	Tonne	·9842
Germany	Pfund	1·0311	Centner	113·426	Schiffpfund	·1519
Greece	Pound	·8811	Oke	2·8	Cantaro	·05
Holland	Pond	2·2046	—	—	—	—
Madras	Seer	·625	Maund	25	Candy	·2232
Portugal	Arratel	1·0119	Arroba	32·3795	Quintal	·0578
Russia	Funt	·90264	Pud	36·1056	Packen	·4836
Spain	Marco	·5072	Libra	1·0144	Quintal	·0453
Sweden	Skälpund	·9376	Lispund	18·752	Skeppund	·1674

ENGLISH COINS.

POUND STERLING.

Pure gold in sovereign = 113·001 Troy grains.
Copper alloy in sovereign = 10·273 „
Fineness of sovereign = 22 carats = ·916⅔.
Total weight of sovereign = 123·273 Troy grains.

SILVER.

Weight of pure silver in half-crown = 201·8 Troy grains.
„ „ shilling = 80·7 „
„ „ sixpence = 40·3 „
Total weight of shilling = 87·273 „

A pound Avoirdupois of copper is coined in 24 pence or 48 halfpennies.

Table showing Rates of Discount at Various Percentages.

Amount of Account	£5 per Cent.	£7½ per Cent.	£10 per Ct.	£12½ per Cent.	£15 per Cent.	£20 per Cent.	£25 per Cent
£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
0 2 6	0 0 1½	0 0 2¼	0 0 3	0 0 3¾	0 0 4½	0 0 6	0 0 7½
0 5 0	0 0 3	0 0 4½	0 0 6	0 0 7½	0 0 9	0 1 0	0 1 3
0 10 0	0 0 6	0 0 9	0 1 0	0 1 3	0 1 6	0 2 0	0 2 6
0 15 0	0 0 9	0 1 1½	0 1 6	0 1 10½	0 2 3	0 3 0	0 3 9
1 0 0	0 1 0	0 1 6	0 2 0	0 2 6	0 3 0	0 4 0	0 5 0
1 10 0	0 1 6	0 2 3	0 3 0	0 3 9	0 4 6	0 6 0	0 7 6
1 15 0	0 1 9	0 2 7½	0 3 6	0 4 4½	0 5 3	0 7 0	0 8 9
2 0 0	0 2 0	0 3 0	0 4 0	0 5 0	0 6 0	0 8 0	0 10 0
2 10 0	0 2 6	0 3 9	0 5 0	0 6 3	0 7 6	0 10 0	0 12 6
2 15 0	0 2 9	0 4 1½	0 5 6	0 6 10½	0 8 3	0 11 0	0 13 9
3 0 0	0 3 0	0 4 6	0 6 0	0 7 6	0 9 0	0 12 0	0 15 0
3 10 0	0 3 6	0 5 3	0 7 0	0 8 9	0 10 6	0 14 0	0 17 6
3 15 0	0 3 9	0 5 7½	0 7 6	0 9 4½	0 11 3	0 15 0	0 18 9
4 0 0	0 4 0	0 6 0	0 8 0	0 10 0	0 12 0	0 16 0	1 0 0
4 10 0	0 4 6	0 6 9	0 9 0	0 11 3	0 13 6	0 18 0	1 2 6
4 15 0	0 4 9	0 7 1½	0 9 6	0 11 10½	0 14 3	0 19 0	1 3 9
5 0 0	0 5 0	0 7 6	0 10 0	0 12 6	0 15 0	1 0 0	1 5 0
5 10 0	0 5 6	0 8 3	0 11 0	0 13 9	0 16 6	1 2 0	1 7 6
5 15 0	0 5 9	0 8 7½	0 11 6	0 14 4½	0 17 3	1 3 0	1 8 9
6 0 0	0 6 0	0 9 0	0 12 0	0 15 0	0 18 0	1 4 0	1 10 0
6 10 0	0 6 6	0 9 9	0 13 0	0 16 3	0 19 6	1 6 0	1 12 6
6 15 0	0 6 9	0 10 1½	0 13 6	0 16 10½	1 0 3	1 7 0	1 13 9
7 0 0	0 7 0	0 10 6	0 14 0	0 17 6	1 1 0	1 8 0	1 15 0
7 10 0	0 7 6	0 11 3	0 15 0	0 18 9	1 2 6	1 10 0	1 17 6
8 0 0	0 8 0	0 12 0	0 16 0	1 0 0	1 4 0	1 12 0	2 0 0
8 10 0	0 8 6	0 12 9	0 17 0	1 1 3	1 5 6	1 14 0	2 2 6
9 0 0	0 9 0	0 13 6	0 18 0	1 2 6	1 7 0	1 16 0	2 5 0
9 10 0	0 9 6	0 14 3	0 19 0	1 3 9	1 8 6	1 18 0	2 7 6
10 0 0	0 10 0	0 15 0	1 0 0	1 5 0	1 10 0	2 0 0	2 10 0
10 10 0	0 10 6	0 15 9	1 1 0	1 6 3	1 11 6	2 2 0	2 12 6
11 0 0	0 11 0	0 16 6	1 2 0	1 7 6	1 13 0	2 4 0	2 15 0
11 10 0	0 11 6	0 17 3	1 3 0	1 8 9	1 14 6	2 6 0	2 17 6
12 0 0	0 12 0	0 18 0	1 4 0	1 10 0	1 16 0	2 8 0	3 0 0
12 10 0	0 12 6	0 18 9	1 5 0	1 11 3	1 17 6	2 10 0	3 2 6
13 0 0	0 13 0	0 19 6	1 6 0	1 12 6	1 19 0	2 12 0	3 5 0
13 10 0	0 13 6	1 0 3	1 7 0	1 13 9	2 0 6	2 14 0	3 7 6
14 0 0	0 14 0	1 1 0	1 8 0	1 15 0	2 2 0	2 16 0	3 10 0
14 10 0	0 14 6	1 1 9	1 9 0	1 16 3	2 3 6	2 18 0	3 12 6
15 0 0	0 15 0	1 2 6	1 10 0	1 17 6	2 5 0	3 0 0	3 15 0
20 0 0	1 0 0	1 10 0	2 0 0	2 10 0	3 0 0	4 0 0	5 0 0
30 0 0	1 10 0	2 5 0	3 0 0	3 15 0	4 10 0	6 0 0	7 10 0
40 0 0	2 0 0	3 0 0	4 0 0	5 0 0	6 0 0	8 0 0	10 0 0
50 0 0	2 10 0	3 15 0	5 0 0	6 5 0	7 10 0	10 0 0	12 10 0
60 0 0	3 0 0	4 10 0	6 0 0	7 10 0	9 0 0	12 0 0	15 0 0
70 0 0	3 10 0	5 5 0	7 0 0	8 15 0	10 10 0	14 0 0	17 10 0
80 0 0	4 0 0	6 0 0	8 0 0	10 0 0	12 0 0	16 0 0	20 0 0
90 0 0	4 10 0	6 15 0	9 0 0	11 5 0	13 10 0	18 0 0	22 10 0

TIMBER LOADS.

One ton of Ebony	= 26–30 c. feet	One ton of Baltic Fir	= 50 58 c. feet
„ „ Oak	= 32–40 „	„ „ Elm	= 53–59 „
„ „ Mahogany	= 32–50 „	„ „ Pine	= 55–60 „
„ „ Ash	= 36–45 „	„ „ Deals	= 55–65 „
„ „ Beech	= 42–50 „	„ „ Lime-tree	= 56–59 „
„ „ Maple	= 46–49 „	„ „ Scotch Fir	= 60–66 „
„ „ Walnut	= 50–54 „		

WEIGHT OF EARTH, ROCKS, ETC., PER CUBIC YARD.

Sand	about 30 cwt.	Sandstone . . .	about 39 cwt
Gravel . . .	„ 30 „	Shale . . .	„ 40 „
Mud	„ 25 „	Quartz . . .	„ 41 „
Marl . . .	„ 26 „	Granite . . .	„ 42 „
Clay	„ 31 „	Trap	„ 42 „
Chalk . . .	„ 36 „	Slate . . .	„ 43 „

TABLE OF THE POINTS OF THE COMPASS AND THEIR ANGLES WITH THE MERIDIAN.

North		Points	°	′	″	Points	South	
		0¼	2	48	45	0¼		
		0½	5	37	30	0½		
		0¾	8	26	15	0¾		
N. by E.	N. by W.	1	11	15	0	1	S. by E.	S. by W.
		1¼	14	3	45	1¼		
		1½	16	52	30	1½		
		1¾	19	41	15	1¾		
NNE.	NNW.	2	22	30	0	2	SSE.	SSW.
		2¼	25	18	45	2¼		
		2½	28	7	30	2½		
		2¾	30	56	15	2¾		
NE. by N.	NW. by N.	3	33	45	0	3	SE. by S.	SW. by S.
		3¼	36	33	45	3¼		
		3½	39	22	30	3½		
		3¾	42	11	15	3¾		
NE.	NW.	4	45	0	0	4	SE.	SW.
		4¼	47	48	45	4¼		
		4½	50	37	30	4½		
		4¾	53	26	15	4¾		
NE. by E.	NW. by W.	5	56	15	0	5	SE. by E.	SW. by W.
		5¼	59	3	45	5¼		
		5½	61	52	30	5½		
		5¾	64	41	15	5¾		
ENE.	WNW.	6	67	30	0	6	ESE.	WSW.
		6¼	70	18	45	6¼		
		6½	73	7	30	6½		
		6¾	75	56	15	6¾		
E. by N.	W. by N.	7	78	45	0	7	E. by S.	W. by S.
		7¼	81	33	45	7¼		
		7½	84	22	30	7½		
		7¾	87	11	15	7¾		
East	West	8	90	0	0	8	East	West

TABLE OF INCOME, WAGES, OR EXPENSES.

Per Year		Per Month			Per Week			Per Day			Per Year		Per Month			Per Week			Per Day		
£	s.	£	s.	d.	£	s.	d.	£	s.	d.	£		£	s.	d.	£	s.	d.	£	s.	d.
1	0	0	1	8	0	0	4½	0	0	0¾	13	0	1	1	8	0	5	0	0	0	8½
1	10	0	2	6	0	0	7	0	0	1	13	13	1	2	9	0	5	3	0	0	9
2	0	0	3	4	0	0	9¼	0	0	1¼	14	0	1	3	4	0	5	4½	0	0	9¼
2	2	0	3	6	0	0	9¾	0	0	1½	14	14	1	4	6	0	5	8	0	0	9¾
2	10	0	4	2	0	0	11½	0	0	1¾	15	0	1	5	0	0	5	9	0	0	10
3	0	0	5	0	0	1	1¾	0	0	2	15	15	1	6	3	0	6	0½	0	0	10¼
3	3	0	5	3	0	1	2½	0	0	2	16	0	1	6	8	0	6	2	0	0	10½
3	10	0	5	10	0	1	4¼	0	0	2¼	16	16	1	8	0	0	6	5½	0	0	11
4	0	0	6	8	0	1	6½	0	0	2¾	17	0	1	8	4	0	6	6	0	0	11½
4	4	0	7	0	0	1	7½	0	0	2¾	17	17	1	9	9	0	6	10	0	0	11¾
4	10	0	7	6	0	1	8¾	0	0	3	18	0	1	10	0	0	6	11	0	0	11¾
5	0	0	8	4	0	1	11	0	0	3¼	18	18	1	11	6	0	7	3	0	1	0½
5	5	0	8	9	0	2	0¼	0	0	3½	19	0	1	11	8	0	7	3½	0	1	0½
5	10	0	9	2	0	2	1½	0	0	3¾	20	0	1	13	4	0	7	8	0	1	1¼
6	0	0	10	0	0	2	3¾	0	0	4	30	0	2	10	0	0	11	6	0	1	7¾
6	6	0	10	6	0	2	5	0	0	4¼	40	0	3	6	8	0	15	4½	0	2	2¼
6	10	0	10	10	0	2	6	0	0	4¼	50	0	4	3	4	0	19	3	0	2	9
7	0	0	11	8	0	2	8¼	0	0	4½	60	0	5	0	0	1	3	0¾	0	3	3½
7	7	0	12	3	0	2	10	0	0	4¾	70	0	5	16	8	1	6	11	0	3	10
7	10	0	12	6	0	2	10½	0	0	5	80	0	6	13	4	1	10	9	0	4	4½
8	0	0	13	4	0	3	1	0	0	5¼	90	0	7	10	0	1	14	7¼	0	4	11
8	8	0	14	0	0	3	2¾	0	0	5½	100	0	8	6	8	1	18	5	0	5	5¾
8	10	0	14	2	0	3	3¼	0	0	5½	200	0	16	13	4	3	16	11	0	10	11½
9	0	0	15	0	0	3	5½	0	0	6	300	0	25	0	0	5	15	4½	0	16	5¼
9	9	0	15	9	0	3	7½	0	0	6¼	400	0	33	6	8	7	13	10	1	1	11
10	0	0	16	8	0	3	10	0	0	6½	500	0	41	13	4	9	12	3½	1	7	4¾
10	10	0	17	6	0	4	0½	0	0	7	600	0	50	0	0	11	10	9	1	12	10½
11	0	0	18	4	0	4	3	0	0	7¼	700	0	58	6	8	13	9	2¾	1	18	4¼
11	11	0	19	3	0	4	5½	0	0	7½	800	0	66	13	4	15	7	8¼	2	3	10
12	0	1	0	0	0	4	7½	0	0	8	900	0	75	0	0	17	6	1¾	2	9	3¼
12	12	1	1	0	0	4	10	0	0	8¼	1,000	0	83	6	8	19	4	7¼	2	14	9½

TABLE OF THE DECIMAL EQUIVALENTS OF PENCE AND SHILLINGS.

Pence	Shillings	Pence	Shillings	Pence	Shillings	Pence	Shillings
¼	·0208333	3¼	·2708333	6¼	·5208333	9¼	·7708333
½	·0416666	3½	·2916666	6½	·5416666	9½	·7916666
¾	·0625000	3¾	·3125000	6¾	·5625000	9¾	·8125000
1	·0833333	4	·3333333	7	·5833333	10	·8333333
1¼	·1041666	4¼	·3541666	7¼	·6041666	10¼	·8541666
1½	·1250000	4½	·3750000	7½	·6250000	10½	·8750000
1¾	·1458333	4¾	·3958333	7¾	·6458333	10¾	·8958333
2	·1666666	5	·4166666	8	·6666666	11	·9166666
2¼	·1875000	5¼	·4375000	8¼	·6875000	11¼	·9375000
2½	·2083333	5½	·4583333	8½	·7083333	11½	·9583333
2¾	·2291666	5¾	·4791666	8¾	·7291666	11¾	·9791666
3	·2500000	6	·5000000	9	·7500000	12	1·0000000

Table of the Circular Measure, or Length of Circular Arc subtending any Angle, Radius being unity.

To calculate the circular measure of any angle, see 'Trigonometry' (pp. 8 and 9).

Use of the Table.—*Ex.* : Required to find the length of the circular arc subtending an angle of 40° 11′ 15″ on a circle of 560 feet radius.

Tabular No. for 40° = ·698131701
" " 11′ = ·003199770
" " 15″ = ·000072722

Length of arc = (560 × ·701404193) = 392·78634808 ft.

Seconds.

Sec.	Circ. Meas.	Sec.	Circ. Meas.	Sec.	Circ. Meas.	Sec.	Circ. Meas.
1	·0000048481	16	·0000775701	31	·0001502922	46	·0002230143
2	·0000096963	17	·0000824183	32	·0001551404	47	·0002278624
3	·0000145444	18	·0000872665	33	·0001599885	48	·0002327106
4	·0000193925	19	·0000921146	34	·0001648367	49	·0002375587
5	·0000242407	20	·0000969627	35	·0001696848	50	·0002424068
6	·0000290888	21	·0001018109	36	·0001745329	51	·0002472550
7	·0000339369	22	·0001066591	37	·0001793811	52	·0002521031
8	·0000387850	23	·0001115071	38	·0001842291	53	·0002569513
9	·0000436332	24	·0001163553	39	·0001890773	54	·0002617994
10	·0000484814	25	·0001212034	40	·0001939255	55	·0002666475
11	·0000533295	26	·0001260516	41	·0001987736	56	·0002714957
12	·0000581776	27	·0001308997	42	·0002036217	57	·0002763437
13	·0000630258	28	·0001357478	43	·0002084699	58	·0002811919
14	·0000678739	29	·0001405960	44	·0002133180	59	·0002860401
15	·0000727221	30	·0001454441	45	·0002181662	60	·0002908882

Minutes.

M.	Circ. Meas.	M.	Circ. Meas.	M.	Circ. Meas.	M.	Circ. Meas.
1	·0002908882	16	·0046542113	31	·0090175345	46	·0133808576
2	·0005817764	17	·0049450995	32	·0093084227	47	·0136717458
3	·0008726646	18	·0052359878	33	·0095993109	48	·01396263401
4	·0011635528	19	·0055268760	34	·0098901991	49	·0142535222
5	·0014544410	20	·0058177642	35	·0101810873	50	·0145444104
6	·0017453293	21	·0061086524	36	·0104719755	51	·0148352986
7	·0020362175	22	·0063995406	37	·0107628637	52	·0151261869
8	·0023271057	23	·0066904288	38	·0110537519	53	·0154170751
9	·0026179939	24	·0069813170	39	·0113446401	54	·0157079633
10	·0029088821	25	·0072722052	40	·0116355283	55	·0159988515
11	·0031997703	26	·0075630934	41	·0119264166	56	·0162897397
12	·0034906585	27	·0078539816	42	·0122173048	57	·0165806279
13	·0037815467	28	·0081448698	43	·0125081921	58	·0168715161
14	·0040724349	29	·0084357581	44	·0127990812	59	·0171624043
15	·0043633231	30	·0087266463	45	·0130899694	60	·0174532925

TABLE OF THE CIRCULAR MEASURE OF ANY ANGLE (continued).

DEGREES.

Deg.	Circ. Meas.	Deg.	Circ. Meas.	Deg.	Circ. Meas.	Deg.	Circ. Meas.
1	·017453293	46	·802851456	91	1·588249619	136	2·373647783
2	·034906585	47	·820304748	92	1·605702912	137	2·391101075
3	·052359878	48	·837758041	93	1·623156204	138	2·408554368
4	·069813170	49	·855211333	94	1·640609497	139	2·426007660
5	·087266463	50	·872664626	95	1·658062789	140	2·443460953
6	·104719755	51	·890117919	96	1·675516082	141	2·460914245
7	·122173048	52	·907571211	97	1·692969374	142	2·478367538
8	·139626340	53	·925024504	98	1·710422667	143	2·495820830
9	·157079633	54	·942477796	99	1·727875959	144	2·513274123
10	·174532925	55	·959931089	100	1·745329252	145	2·530727415
11	·191986218	56	·977384381	101	1·762782545	146	2·548180708
12	·209439510	57	·994837674	102	1·780235837	147	2·56563400
13	·226892803	58	1·012290966	103	1·797689130	148	2·583087293
14	·244346095	59	1·029744259	104	1·815142422	149	2·600540585
15	·261799388	60	1·047197551	105	1·832595715	150	2·617993878
16	·279252680	61	1·064650844	106	1·850049007	151	2·635447170
17	·296705973	62	1·082104136	107	1·867502300	152	2·652900463
18	·314159265	63	1·099557429	108	1·884955592	153	2·670353756
19	·331612558	64	1·117010721	109	1·902408885	154	2·687807048
20	·349065850	65	1·134464014	110	1·919862177	155	2·705260340
21	·366519143	66	1·151917306	111	1·937315470	156	2·722713633
22	·383972435	67	1·169370599	112	1·954768762	157	2·740166926
23	·401425728	68	1·186823891	113	1·972222055	158	2·757620218
24	·418879020	69	1·204277184	114	1·989675347	159	2·775073511
25	·436332313	70	1·221730476	115	2·007128640	160	2·792526803
26	·453785606	71	1·239183769	116	2·024581932	161	2·809980096
27	·471238898	72	1·256637061	117	2·042035225	162	2·827433388
28	·488692191	73	1·274090354	118	2·059488517	163	2·844886681
29	·506145483	74	1·291543646	119	2·076941810	164	2·862339973
30	·523598776	75	1·308996939	120	2·094395102	165	2·879793266
31	·541052068	76	1·326450232	121	2·111848395	166	2·897246558
32	·558505361	77	1·343903524	122	2·129301687	167	2·914699851
33	·575958653	78	1·361356817	123	2·146754980	168	2·932153143
34	·593411946	79	1·378810109	124	2·164208272	169	2·949606436
35	·610865238	80	1·396263402	125	2·181661565	170	2·967059728
36	·628318531	81	1·413716694	126	2·199114858	171	2·984513021
37	·645771823	82	1·431169987	127	2·216568150	172	3·001966313
38	·663225116	83	1·448623279	128	2·234021443	173	3·019419606
39	·680678408	84	1·466076572	129	2·251474735	174	3·036872898
40	·698131701	85	1·483529864	130	2·268928028	175	3·054326191
41	·715584993	86	1·500983157	131	2·286381320	176	3·071779484
42	·733038286	87	1·518436449	132	2·303834613	177	3·089232776
43	·750491578	88	1·535889742	133	2·321287905	178	3·106686069
44	·767944871	89	1·553343034	134	2·338741198	179	3·124139361
45	·785398163	90	1·570796327	135	2·356194490	180	3·141592654

Table of the Circular Measure of any Angle (concluded).

DEGREES.

Deg.	Circ. Meas.
181	3·159045946
182	3·176499239
183	3·193952531
184	3·211405824
185	3·228859116
186	3·246312409
187	3·263765701
188	3·281218994
189	3·298672286
190	3·316125579
191	3·333578871
192	3·351032164
193	3·368485456
194	3·385938749
195	3·403392041
196	3·420845334
197	3·438298626
198	3·455751919
199	3·473205211
200	3·490658504
201	3·508111797
202	3·525565089
203	3·543018382
204	3·560471674
205	3·577924967
206	3·595378259
207	3·612831552
208	3·630284844
209	3·647738137
210	3·665191429
211	3·682644722
212	3·700098014
213	3·717551307
214	3·735004599
215	3·752457892
216	3·769911184
217	3·787364477
218	3·804817769
219	3·822271062
220	3·839724354
221	3·857177647
222	3·874630939
223	3·892084232
224	3·909537524
225	3·926990817
226	3·944444110
227	3·961897402
228	3·979350695
229	3·996803987
230	4·014257280
231	4·031710572
232	4·049163865
233	4·066617157
234	4·084070450
235	4·101523742
236	4·118977035
237	4·136430327
238	4·153883620
239	4·171336912
240	4·188790205
241	4·206243497
242	4·223696790
243	4·241150082
244	4·258603375
245	4·276056667
246	4·293509960
247	4·310963252
248	4·328416545
249	4·345869837
250	4·363323130
251	4·380776423
252	4·398229715
253	4·415683008
254	4·433136300
255	4·450589593
256	4·468042885
257	4·485496178
258	4·502949470
259	4·520402763
260	4·537856055
261	4·555309348
262	4·572762640
263	4·590215933
264	4·607669225
265	4·625122518
266	4·642575810
267	4·660029103
268	4·677482395
269	4·694935688
270	4·712388980
271	4·729842273
272	4·747295565
273	4·764748858
274	4·782202150
275	4·799655443
276	4·817108736
277	4·834562028
278	4·852015321
279	4·869468613
280	4·886921906
281	4·904375198
282	4·921828491
283	4·939281783
284	4·956735076
285	4·974188368
286	4·991641661
287	5·009094953
288	5·026548246
289	5·044001538
290	5·061454831
291	5·078908123
292	5·096361416
293	5·113814708
294	5·131268001
295	5·148721293
296	5·166174586
297	5·183627878
298	5·201081171
299	5·218534463
300	5·235987756
301	5·253441049
302	5·270894341
303	5·288347633
304	5·305800926
305	5·323254219
306	5·340707511
307	5·358160804
308	5·375614096
309	5·393067389
310	5·410520681
311	5·427973974
312	5·445427266
313	5·462880559
314	5·480333851
315	5·497787144
316	5·515240436
317	5·532693729
318	5·550147021
319	5·567600314
320	5·585053606
321	5·602506899
322	5·619960191
323	5·637413484
324	5·654866776
325	5·672320069
326	5·689773362
327	5·707226654
328	5·724679947
329	5·742133239
330	5·759586532
331	5·777039824
332	5·794493117
333	5·811946409
334	5·829399702
335	5·846852994
336	5·864306287
337	5·881759579
338	5·899212872
339	5·916666164
340	5·934119457
341	5·951572749
342	5·969026042
343	5·986479334
344	6·003932627
345	6·021385919
346	6·038839212
347	6·056292504
348	6·073745797
349	6·091199089
350	6·108652382
351	6·126105675
352	6·143558967
353	6·161012260
354	6·178465552
355	6·195918845
356	6·213372137
357	6·230825430
358	6·248278722
359	6·265732015
360	6·283185307

TABLE OF THE CIRCUMFERENCES OF CIRCLES, ADVANCING BY 10THS.

Diamr.	Circumferences										Diamr.
	·0	·1	·2	·3	·4	·5	·6	·7	8	·9	
0	·0000	·3142	·6823	·9425	1·2566	1·5708	1·8850	2·1991	2·5133	2·8274	0
1	3·1416	3·4557	3·7699	4·0840	4·3982	4·7124	5·0265	5·3407	5·6548	5·9690	1
2	6·2832	6·5973	6·9115	7·2256	7·5398	7·8540	8·1681	8·4823	8·7964	9·1106	2
3	9·4248	9·7389	10·0531	10·3672	10·6814	10·9956	11·3097	11·6239	11·9380	12·2522	3
4	12·5664	12·8805	13·1947	13·5088	13·8230	14·1372	14·4513	14·7655	15·0796	15·3938	4
5	15·7080	16·0221	16·3363	16·6504	16·9646	17·2788	17·5929	17·9071	18·2212	18·5354	5
6	18·8496	19·1637	19·4779	19·7920	20·1062	20·4204	20·7345	21·0487	21·3628	21·6770	6
7	21·9912	22·3053	22·6195	22·9336	23·2478	23·5620	23·8761	24·1903	24·5044	24·8186	7
8	25·1328	25·4469	25·7611	26·0752	26·3894	26·7036	27·0177	27·3319	27·6460	27·9602	8
9	28·2744	28·5885	28·9027	29·2168	29·5310	29·8452	30·1593	30·4735	30·7876	31·1018	9
10	31·4160	31·7301	32·0443	32·3580	32·6726	32·9868	33·3009	33·6150	33·9292	34·2434	10
11	34·5576	34·8717	35·1859	35·5010	35·8142	36·1284	36·4425	36·7567	37·0708	37·3840	11
12	37·6992	38·0133	38·3275	38·6416	38·9558	39·2700	39·5841	39·8983	40·2124	40·5266	12
13	40·8408	41·1549	41·4691	41·7832	42·0974	42·4116	42·7257	43·0399	43·3540	43·6682	13
14	43·9824	44·2965	44·6107	44·9248	45·2390	45·5532	45·8673	46·1815	46·4956	46·8098	14
15	47·1240	47·4381	47·7523	48·0664	48·3806	48·6948	49·0089	49·3321	49·6372	49·9514	15
16	50·2656	50·5797	50·8939	51·2080	51·5224	51·8364	52·1505	52·4647	52·7788	53·0930	16
17	53·4072	53·7213	54·0355	54·3496	54·6038	54·9780	55·2921	55·6063	55·9204	56·2346	17
18	56·5488	56·8629	57·1771	57·4912	57·8054	58·1196	58·4337	59·7479	59·0620	59·3762	18
19	59·6904	60·0045	60·3187	60·6328	60·9470	61·2612	61·5753	61·8895	62·2036	62·5178	19
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Circumferences										

TABLE OF THE CIRCUMFERENCES OF CIRCLES, ADVANCING BY 10THS (continued).

Diamr.	Circumferences										Diamr.
	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	
20	62·8320	63·1461	63·4603	63·7744	64·0886	64·4028	64·7161	65·0311	65·3452	65·6594	20
21	65·9736	66·2870	66·6012	66·7916	67·2930	67·5444	67·8585	68·1727	68·4868	68·8010	21
22	69·1152	69·4293	69·7435	70·0576	70·3718	70·6860	71·0001	71·3143	71·6284	71·9426	22
23	72·2568	72·5709	72·8851	73·1992	73·5134	73·8276	74·1417	74·4559	74·7680	75·0882	23
24	75·3984	75·7125	76·0267	76·3408	76·6523	76·9692	77·2833	77·5975	77·9116	78·2258	24
25	78·5400	78·8541	79·1683	79·4824	79·7966	80·8108	80·4249	80·7391	81·0532	81·3674	25
26	81·6816	82·3099	82·6240	82·6240	82·9382	83·2524	83·5665	83·8807	84·1948	84·5090	26
27	84·8232	85·1373	85·4515	85·7656	86·0798	86·3940	86·7081	87·0223	87·3364	87·6506	27
28	87·9648	88·2789	88·5931	88·9072	89·2214	89·5315	89·8497	90·1639	90·4780	90·7922	28
29	91·1064	91·4205	91·7347	92·0488	92·3630	92·6772	92·9913	93·3055	93·6196	93·9338	29
30	94·2480	94·5621	94·8763	95·1904	95·5046	95·8188	96·1329	96·4471	96·7612	97·0754	30
31	97·3896	97·7037	98·0179	98·3320	98·6452	98·9604	99·2745	99·5887	99·9028	100·217	31
32	100·531	100·845	101·160	101·474	101·748	102·102	102·416	102·730	103·044	103·359	32
33	103·673	103·987	104·301	104·615	104·929	105·244	105·558	105·872	106·186	106·500	33
34	106·814	107·129	107·427	107·757	108·071	108·385	108·699	109·035	109·308	109·642	34
35	109·956	110·270	110·584	110·898	112·213	111·527	111·841	112·155	112·469	112·783	35
36	113·098	113·412	113·726	114·040	114·354	114·668	114·983	115·297	115·611	115·925	36
37	116·239	116·553	116·868	117·182	117·496	117·810	118·124	118·438	118·752	119·067	37
38	119·381	119·695	120·009	120·323	120·637	120·952	121·266	121·580	121·894	122·208	38
39	122·522	122·837	123·151	123·465	123·779	124·093	124·407	124·722	125·036	125·350	39
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Circumferences										

TABLE OF THE CIRCUMFERENCES OF CIRCLES, ADVANCING BY 10THS (continued).

Diamr.	Circumferences ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
40	125·664	125·978	126·292	126·606	126·921	127·235	127·549	127·863	128·177	128·491	40
41	128·806	129·120	129·432	129·748	130·062	130·376	130·691	131·005	131·319	131·632	41
42	131·947	132·261	132·576	132·890	133·204	133·518	133·832	134·146	134·460	134·775	42
43	135·089	135·403	135·717	136·033	136·345	136·660	136·974	137·288	137·602	137·916	43
44	138·230	138·545	138·859	139·173	139·487	139·801	140·115	140·430	140·744	141·058	44
45	141·372	141·686	142·000	142·314	142·629	142·943	143·257	143·571	143·885	144·199	45
46	144·514	144·828	145·142	145·456	145·770	146·084	146·399	146·713	147·027	147·341	46
47	147·655	147·969	148·284	148·598	148·912	149·226	149·536	149·854	150·168	150·483	47
48	150·797	151·111	151·425	151·739	152·053	152·368	152·682	152·996	153·310	153·624	48
49	153·938	154·253	154·567	154·881	155·195	155·509	155·823	156·138	156·452	156·756	49
50	157·080	157·394	157·708	158·022	158·337	158·651	158·965	159·279	159·593	159·907	50
51	160·222	160·536	160·850	161·164	161·478	161·792	162·107	162·421	162·734	163·049	51
52	163·363	163·677	163·994	164·306	164·620	164·934	165·248	165·562	165·876	166·191	52
53	166·505	166·819	167·133	167·447	167·761	168·076	168·390	168·705	169·018	169·332	53
54	169·646	169·961	170·275	170·589	170·903	171·217	171·531	171·846	172·160	172·474	54
55	172·788	173·102	173·416	173·730	174·045	174·359	174·673	174·977	175·309	175·615	55
56	175·930	176·244	176·558	176·872	177·186	177·500	177·815	178·129	178·443	178·757	56
57	179·071	179·385	179·700	180·014	180·328	180·642	180·956	181·280	181·584	181·899	57
58	182·213	182·527	182·841	183·155	183·469	183·784	184·098	184·412	184·726	185·040	58
59	185·354	185·669	185·983	186·270	186·611	186·925	187·239	187·554	187·868	188·182	59
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Circumferences										

TABLE OF THE CIRCUMFERENCES OF CIRCLES, ADVANCING BY 10THS (continued).

Diamr.	Circumferences ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
60	188·496	188·810	189·124	189·438	189·753	190·067	190·381	190·695	191·009	191·323	60
61	191·638	191·952	192·266	192·580	192·894	193·208	193·523	193·837	194·151	194·465	61
62	194·779	195·093	195·408	195·722	196·036	196·350	196·664	196·978	197·292	197·607	62
63	197·921	198·235	198·549	198·863	199·177	199·492	199·806	200·120	200·434	200·748	63
64	201·062	201·377	201·691	202·005	202·319	202·633	202·947	203·262	203·576	203·890	64
65	204·204	204·518	204·832	205·146	205·461	205·775	206·089	206·403	206·717	207·031	65
66	207·346	207·660	207·974	208·288	208·602	208·916	209·231	209·545	209·859	210·173	66
67	210·487	210·801	211·116	211·430	211·744	212·058	212·372	212·686	213·000	213·315	67
68	213·629	213·943	214·257	214·571	214·885	215·200	215·514	215·828	216·142	216·456	68
69	216·770	217·085	217·399	217·713	218·027	218·341	218·655	218·970	219·284	219·598	69
70	219·912	220·226	220·540	220·854	221·169	221·483	221·797	222·111	222·425	222·739	70
71	223·054	223·368	223·682	223·996	224·310	224·624	224·939	225·253	225·567	225·881	71
72	226·195	226·509	226·824	227·138	227·452	227·766	228·080	228·394	228·708	229·023	72
73	229·337	229·651	229·965	230·279	230·593	230·908	231·222	231·536	231·850	232·164	73
74	232·478	232·793	233·107	233·421	233·735	234·049	234·363	234·678	234·992	235·306	74
75	235·620	235·934	236·248	236·562	236·877	237·191	237·505	237·819	238·133	238·447	75
76	238·762	239·076	239·390	239·704	240·018	240·332	240·647	240·961	241·275	241·599	76
77	241·903	242·217	242·532	242·846	243·160	243·474	243·788	244·102	244·416	244·731	77
78	245·045	245·359	245·673	245·987	246·301	246·616	246·930	247·244	247·548	247·872	78
79	248·186	248·501	248·815	249·129	249·443	249·757	250·071	250·386	250·700	251·014	79
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Circumferences										

TABLE OF THE CIRCUMFERENCES OF CIRCLES, ADVANCING BY 10THS (concluded).

	Circumferences									
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
80	251·328	251·642	251·956	[illegible]	252·585	252·899	253·213	253·527	253·841	254·155
81	254·470	254·784	255·098	[illegible]	255·726	256·040	256·355	256·669	256·983	257·297
82	257·611	257·925	258·240	[illegible]	258·868	259·182	259·496	259·810	260·124	260·439
83	260·753	261·067	261·381	[illegible]	262·009	262·324	262·638	262·952	263·266	263·580
84	263·894	264·209	264·523	[illegible]	265·151	265·465	265·779	266·094	266·408	266·722
85	267·036	267·350	267·664	[illegible]	268·293	268·607	268·921	269·235	269·549	269·863
86	270·178	270·492	270·806	[illegible]	271·434	271·748	272·063	272·377	272·691	273·006
87	273·319	273·633	273·948	[illegible]	274·576	274·890	275·204	275·518	275·833	276·147
88	276·461	276·775	277·089	[illegible]	277·717	278·032	278·346	278·660	278·975	279·288
89	279·602	279·917	280·231	[illegible]	280·859	281·173	281·487	281·802	282·116	282·430
90	282·744	283·058	283·372	[illegible]	284·001	284·315	284·629	284·943	285·257	285·571
91	285·886	286·200	286·514	[illegible]	287·142	287·456	287·771	288·085	288·399	288·713
92	289·027	289·341	289·656	[illegible]	290·284	290·598	290·912	291·226	291·540	291·855
93	292·169	292·483	292·797	[illegible]	293·425	293·740	294·054	294·368	294·682	294·996
94	295·310	295·625	295·939	[illegible]	296·567	296·881	297·196	297·510	297·824	298·138
95	298·452	298·766	299·072	[illegible]	299·709	300·023	300·337	300·651	300·965	301·279
96	301·594	301·908	302·222	[illegible]	302·850	303·164	303·479	303·793	304·107	304·421
97	304·735	305·049	305·364	[illegible]	305·992	306·306	306·620	306·936	307·248	307·563
98	307·877	308·191	308·506	[illegible]	309·133	309·448	309·762	310·076	310·390	310·704
99	311·018	311·333	311·647	[illegible]	312·275	312·589	312·903	313·218	313·532	313·846
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Circumferences									

Table of the Areas of Circles, advancing by 10ths.

Diamr.	Areas ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
0	·0000	·0078	·0314	·0706	·1256	·1963	·2827	·3848	·5026	·6361	0
1	·7854	·9503	1·1309	1·3273	1·5393	1·7671	2·0106	2·2698	2·5446	2·8352	1
2	3·1416	3·4636	3·8013	4·1547	4·5239	4·9087	5·3093	5·7255	6·1575	6·6052	2
3	7·0686	7·5476	8·0424	8·5530	9·0792	9·6211	10·1787	10·7521	11·3411	11·9459	3
4	12·5664	13·2025	13·8544	14·5220	15·2053	15·9043	16·6190	17·3494	18·0956	18·8574	4
5	19·6350	20·4282	21·2372	22·0618	22·9022	23·7583	24·6301	25·5176	26·4208	27·3397	5
6	28·2744	29·2247	30·1907	31·1725	32·1699	33·1831	34·2120	35·2566	36·3168	37·3928	6
7	38·4846	39·5920	40·7151	41·8539	43·0085	44·1787	45·3647	46·5663	47·7837	49·0168	7
8	50·2656	51·5300	52·8102	54·1062	55·4178	56·7451	58·0881	59·4469	60·8213	62·2115	8
9	63·6174	65·0389	66·4762	67·9292	69·3979	70·8823	72·3824	73·8982	75·4298	76·9770	9
10	78·5400	80·1186	81·7130	83·2320	84·9488	86·5903	88·2475	89·9204	91·6090	93·3133	10
11	95·0334	96·7691	98·5205	100·2877	102·0705	103·8691	105·6834	107·5134	109·3590	111·2204	11
12	113·0976	114·9904	116·8989	118·8231	120·7631	122·7187	124·6901	126·6771	128·6799	130·6984	12
13	132·7326	134·7824	136·8480	138·9294	141·0264	143·1391	145·2675	147·4117	149·5715	151·7471	13
14	153·9384	156·1453	158·3680	160·6064	162·8605	165·1303	167·4158	169·7170	172·0340	174·3666	14
15	176·7150	179·0790	181·4588	183·8542	186·2654	188·6923	191·1349	193·5932	196·0672	198·5569	15
16	201·0624	203·5835	206·1209	208·6723	211·1411	213·8251	216·4248	219·0402	221·6712	224·3189	16
17	226·9086	229·6588	232·3527	235·0623	237·7877	240·5287	243·2855	246·0579	248·8461	251·6500	17
18	254·4696	257·3048	260·1558	263·0226	265·9050	268·8031	271·7169	274·6465	277·5917	280·5527	18
19	283·5294	286·5217	289·5298	292·5536	295·5931	298·6483	301·7192	304·8060	307·9082	311·0252	19
Diamr.	·0 Areas	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.

TABLE OF THE AREAS OF CIRCLES, ADVANCING BY 10THS (continued).

Diamr.	Areas ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
20	314·1600	317·3094	320·4746	323·6554	326·8520	330·0643	333·2923	336·3360	339·7954	343·0705	20
21	346·3614	349·6679	352·9901	356·3281	359·6817	363·0511	366·4362	369·8370	373·2534	376·6856	21
22	380·1336	383·5972	387·0765	390·5751	394·0823	397·6087	401·1509	404·7087	408·2823	411·8716	22
23	415·4766	419·0972	422·7336	426·3858	430·0536	433·7371	437·4363	441·1511	444·8819	448·6283	23
24	452·3904	456·1681	459·9616	463·7708	467·5957	471·4363	475·2926	479·1646	483·0524	486·9558	24
25	490·8750	494·8098	498·7604	502·7266	506·7086	510·7063	514·7196	518·7488	522·7936	526·8541	25
26	530·9304	535·0223	539·1299	543·2533	547·3923	551·5471	555·7176	559·9038	564·1056	568·3232	26
27	572·5566	576·8056	581·0703	585·3507	589·6469	593·9587	598·2863	602·6295	606·9885	611·3632	27
28	615·7536	620·1596	624·5814	629·0190	633·4722	637·9411	642·4257	646·9261	651·4421	655·9739	28
29	660·5214	665·0845	669·6634	674·2580	678·8683	683·4943	688·1360	692·7934	697·4666	702·1554	29
30	706·8600	711·5802	716·3162	721·0678	725·8352	730·6183	735·4171	740·2316	745·0618	749·9077	30
31	754·7694	759·6467	764·5397	769·4485	774·3729	779·3131	784·2689	789·2406	794·2278	799·2308	31
32	804·2496	809·2840	814·3341	819·3999	824·4815	829·5787	834·6917	839·8203	844·9647	850·1248	32
33	855·3006	860·4920	865·6992	870·9222	876·1608	881·4151	886·6851	891·9709	897·2723	902·5895	33
34	907·9224	913·2709	918·6352	924·0115	929·4109	934·8223	940·2494	945·6922	951·1508	956·6250	34
35	962·1150	967·6206	973·1420	978·6790	984·2318	989·8003	995·3845	1000·984	1006·600	1012·231	35
36	1017·878	1023·541	1029·220	1034·913	1040·624	1046·349	1052·090	1057·8474	1063·620	1069·408	36
37	1075·213	1081·032	1086·868	1092·719	1098·586	1104·469	1110·367	1116·281	1122·211	1128·156	37
38	1134·118	1140·095	1146·087	1152·095	1158·119	1164·159	1170·215	1176·286	1182·373	1188·465	38
39	1194·589	1200·727	1206·877	1213·042	1219·224	1225·420	1231·633	1237·861	1244·121	1250·365	39
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Areas										

TABLE OF THE AREAS OF CIRCLES, ADVANCING BY 10THS (continued).

Diameter	Areas ·1	·2	·3	·4	·5	·6	·7	·8	·9
40	262·931	1269·239	1275·600	1281·900	1288·202	1294·622	1301·007	1307·408	1313·826
41	326·706	1333·109	1339·640	1346·144	1352·666	1359·183	1365·724	1372·287	1378·866
42	392·061	1398·672	1405·305	1411·961	1418·629	1425·313	1432·013	1438·727	1445·466
43	458·967	1465·745	1472·550	1479·340	1486·173	1493·014	1499·871	1506·743	1513·630
44	527·464	1534·389	1541·340	1548·306	1555·288	1562·286	1569·300	1576·329	1583·374
45	597·811	1604·594	1611·711	1618·936	1625·974	1633·129	1640·302	1647·490	1654·689
46	669·140	1676·389	1683·654	1690·936	1698·231	1705·543	1712·871	1720·214	1727·574
47	742·330	1749·746	1757·168	1764·606	1772·059	1779·528	1787·013	1794·513	1802·030
48	817·100	1824·673	1832·262	1839·867	1847·487	1855·123	1862·726	1870·393	1878·080
49	893·450	1901·171	1908·907	1916·659	1924·426	1932·210	1940·009	1947·823	1955·654
50	971·382	1979·239	1987·123	1995·042	2002·966	2010·907	2018·863	2026·836	2034·824
51	050·844	2058·878	2066·929	2074·996	2083·077	2091·176	2099·289	2107·417	2115·561
52	131·898	2140·082	2148·282	2156·520	2164·750	2173·018	2181·304	2189·570	2197·871
53	214·522	2222·870	2231·233	2239·615	2248·011	2256·423	2264·870	2273·293	2281·752
54	298·717	2307·222	2315·744	2324·281	2332·834	2341·403	2349·987	2358·588	2367·203
55	384·483	2393·143	2401·824	2410·519	2419·230	2427·954	2436·699	2445·458	2454·236
56	471·819	2480·639	2489·475	2498·326	2507·193	2516·076	2524·974	2533·889	2542·819
57	560·726	2569·703	2578·696	2587·705	2596·729	2605·769	2614·824	2623·896	2632·983
58	651·205	2660·326	2669·460	2678·614	2687·836	2697·082	2706·248	2715·473	2724·716
59	743·253	2752·544	2761·851	2771·174	2780·512	2789·866	2799·236	2808·622	2818·023
Diameter	·1	·2	·3	·4	·5	·6	·7	·8	·9

TABLE OF THE AREAS OF CIRCLES, ADVANCING BY 10THS (continued).

Diamr.	Areas ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
60	2827·440	2836·873	2846·321	2855·785	2865·265	2874·760	2884·262	2893·798	2903·341	2912·899	60
61	2922·473	2932·063	2941·669	2957·290	2960·927	2970·579	2980·247	2989·931	2999·630	3009·346	61
62	3019·078	3028·824	3038·587	3048·365	3058·159	3067·969	3077·794	3087·634	3097·492	3107·364	62
63	3117·253	3127·156	3137·076	3147·011	3156·966	3166·929	3176·912	3186·910	3196·924	3206·953	63
64	3216·998	3227·059	3237·136	3247·228	3257·337	3267·460	3277·600	3287·755	3297·926	3308·113	64
65	3318·315	3328·534	3338·767	3349·016	3359·281	3369·562	3379·859	3390·171	3400·499	3410·843	65
66	3421·202	3431·578	3441·963	3452·375	3462·797	3473·235	3483·689	3494·164	3504·643	3515·143	66
67	3525·661	3536·193	3546·741	3557·304	3567·884	3578·479	3589·090	3599·716	3610·358	3621·016	67
68	3631·690	3642·379	3653·084	3663·804	3674·541	3685·293	3696·006	3706·845	3717·644	3728·459	68
69	3739·289	3750·136	3760·998	3771·876	3782·769	3793·678	3804·603	3815·544	3826·500	3837·472	69
70	3848·460	3859·495	3870·483	3881·517	3892·568	3903·634	3914·716	3925·814	3936·927	3948·057	70
71	3959·201	3970·362	3981·538	3992·730	4003·937	4015·161	4026·400	4037·655	4048·925	4060·212	71
72	4071·514	4082·833	4094·165	4105·513	4116·879	4128·259	4139·652	4151·067	4162·494	4173·938	72
73	4185·397	4196·871	4208·361	4219·868	4231·390	4242·927	4254·480	4266·049	4277·634	4289·234	73
74	4300·850	4312·482	4324·130	4335·793	4347·472	4359·166	4370·877	4382·603	4394·345	4406·102	74
75	4417·875	4429·664	4441·468	4453·289	4465·125	4476·976	4488·844	4500·727	4512·626	4524·540	75
76	4536·470	4548·416	4560·379	4572·355	4584·358	4596·357	4608·382	4620·422	4632·478	4644·549	76
77	4656·637	4668·740	4680·858	4692·993	4705·143	4717·309	4729·490	4741·688	4753·961	4766·129	77
78	4778·374	4790·634	4802·909	4815·201	4827·508	4839·831	4852·170	4864·524	4876·897	4889·280	78
79	4901·681	4914·099	4926·531	4938·982	4951·444	4963·924	4976·484	4988·931	5001·459	5014·001	79
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Areas										

TABLE OF THE AREAS OF CIRCLES, ADVANCING BY 10THS (concluded).

Diamr.	Areas ·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
80	5026·560	5039·134	5051·724	5064·330	5076·955	5089·588	5102·241	5114·910	5127·594	5140·294	80
81	5153·009	5165·741	5178·488	5191·251	5204·029	5216·823	5229·633	5242·459	5255·300	5268·157	81
82	5281·030	5293·918	5306·822	5319·744	5332·678	5345·629	5358·596	5371·598	5384·576	5397·591	82
83	5410·621	5423·666	5436·727	5449·804	5462·897	5476·005	5489·129	5502·269	5515·424	5528·596	83
84	5541·702	5554·985	5568·203	5581·437	5594·687	5607·952	5621·233	5634·568	5647·843	5661·171	84
85	5674·515	5687·875	5701·250	5714·641	5728·048	5741·470	5754·909	5768·362	5781·832	5795·317	85
86	5808·818	5822·335	5835·868	5849·416	5862·980	5876·559	5890·154	5903·765	5917·392	5931·034	86
87	5944·693	5958·364	5972·056	5985·769	5999·482	6013·219	6026·971	6040·739	6054·515	6068·322	87
88	6082·138	6095·968	6109·815	6123·677	6137·555	6151·449	6165·359	6179·284	6193·225	6207·181	88
89	6221·153	6235·141	6249·145	6263·164	6277·200	6291·204	6305·317	6319·399	6333·497	6347·681	89
90	6361·740	6375·885	6390·046	6404·222	6418·414	6432·622	6446·844	6461·085	6475·340	6489·611	90
91	6503·897	6518·200	6532·517	6546·891	6561·208	6575·565	6589·946	6604·322	6618·754	6633·182	91
92	6647·626	6662·085	6676·560	6691·016	6705·557	6720·079	6734·617	6749·170	6763·739	6778·324	92
93	6792·925	6807·541	6822·173	6836·821	6851·484	6866·163	6880·858	6895·569	6910·295	6925·037	93
94	6939·794	6954·568	6969·357	6984·161	6998·982	7013·818	7028·670	7043·503	7058·418	7073·320	94
95	7088·235	7103·165	7118·112	7133·073	7148·051	7163·044	7178·053	7193·078	7208·118	7223·175	95
96	7238·246	7253·334	7268·437	7283·556	7298·691	7313·841	7329·007	7344·189	7359·386	7374·600	96
97	7389·829	7405·073	7420·334	7435·610	7450·901	7466·209	7481·532	7496·871	7512·225	7527·596	97
98	7542·982	7558·383	7573·801	7589·234	7604·683	7620·147	7635·627	7651·193	7666·635	7682·162	98
99	7697·705	7713·264	7728·839	7744·429	7760·035	7775·656	7791·294	7806·947	7822·615	7838·300	99
Diamr.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9	Diamr.
	Areas										

Table of the Areas of the Segments of a Circle, the Diameter being Unity.

To find the area of the segment of any circle from the following tables.

Rule.—Divide the height of the segment by the diameter, take out the corresponding tabular area, which multiply by the square of the diameter for the result.

H/D	Area	H/D	Area	H/D	Area	H/D	Area
·001	·000042	·038	·009763	·075	·026761	·112	·048262
·002	·000119	·039	·010148	·076	·027289	·113	·048894
·003	·000219	·040	·010537	·077	·027821	·114	·049528
·004	·000337	·041	·010931	·078	·028356	·115	·050165
·005	·000470	·042	·011330	·079	·028894	·116	·050804
·006	·000618	·043	·011734	·080	·029435	·117	·051446
·007	·000779	·044	·012142	·081	·029979	·118	·052090
·008	·000951	·045	·012554	·082	·030526	·119	·052736
·009	·001135	·046	·012971	·083	·031076	·120	·053385
·010	·001329	·047	·013392	·084	·031629	·121	·054036
·011	·001533	·048	·013818	·085	·032186	·122	·054689
·012	·001746	·049	·014247	·086	·032745	·123	·055345
·013	·001968	·050	·014681	·087	·033307	·124	·056003
·014	·002199	·051	·015119	·088	·033872	·125	·056663
·015	·002438	·052	·015561	·089	·034441	·126	·057326
·016	·002685	·053	·016007	·090	·035011	·127	·057991
·017	·002940	·054	·016457	·091	·035585	·128	·058658
·018	·003202	·055	·016911	·092	·036162	·129	·059327
·019	·003471	·056	·017369	·093	·036741	·130	·059999
·020	·003748	·057	·017831	·094	·037323	·131	·060672
·021	·004031	·058	·018296	·095	·037909	·132	·061348
·022	·004322	·059	·018766	·096	·038496	·133	·062026
·023	·004618	·060	·019239	·097	·039087	·134	·062707
·024	·004921	·061	·019716	·098	·039680	·135	·063389
·025	·005230	·062	·020196	·099	·040276	·136	·064074
·026	·005546	·063	·020680	·100	·040875	·137	·064760
·027	·005867	·064	·021168	·101	·041476	·138	·065449
·028	·006194	·065	·021659	·102	·042080	·139	·066140
·029	·006527	·066	·022154	·103	·042687	·140	·066833
·030	·006865	·067	·022652	·104	·043296	·141	·067528
·031	·007209	·068	·023154	·105	·043908	·142	·068225
·032	·007558	·069	·023659	·106	·044522	·143	·068924
·033	·007913	·070	·024168	·107	·045139	·144	·069625
·034	·008273	·071	·024680	·108	·045759	·145	·070328
·035	·008638	·072	·025195	·109	·046381	·146	·071033
·036	·009008	·073	·025714	·110	·047005	·147	·071741
·037	·009383	·074	·026236	·111	·047632	·148	·072450

TABLE OF THE AREAS OF THE SEGMENTS OF A CIRCLE, THE DIAMETER BEING UNITY (continued).

H/D	Area	H/D	Area	H/D	Area	H/D	Area
·149	·073161	·193	·106261	·237	·142387	·281	·180918
·150	·073874	·194	·107051	·238	·143238	·282	·181817
·151	·074589	·195	·107842	·239	·144091	·283	·182718
·152	·075306	·196	·108636	·240	·144944	·284	·183619
·153	·076026	·197	·109430	·241	·145799	·285	·184521
·154	·076747	·198	·110226	·242	·146655	·286	·185425
·155	·077469	·199	·111024	·243	·147512	·287	·186329
·156	·078194	·200	·111823	·244	·148371	·288	·187234
·157	·078921	·201	·112624	·245	·149230	·289	·188140
·158	·079649	·202	·113426	·246	·150091	·290	·189047
·159	·080380	·203	·114230	·247	·150953	·291	·189955
·160	·081112	·204	·115035	·248	·151816	·292	·190864
·161	·081846	·205	·115842	·249	·152680	·293	·191775
·162	·082582	·206	·116650	·250	·153546	·294	·192684
·163	·083320	·207	·117460	·251	·154412	·295	·193596
·164	·084059	·208	·118271	·252	·155280	·296	·194509
·165	·084801	·209	·119083	·253	·156149	·297	·195422
·166	·085544	·210	·119897	·254	·157019	·298	·196337
·167	·086289	·211	·120712	·255	·157890	·299	·197252
·168	·087036	·212	·121529	·256	·158762	·300	·198168
·169	·087785	·213	·122347	·257	·159636	·301	·199085
·170	·088535	·214	·123167	·258	·160510	·302	·200003
·171	·089287	·215	·123988	·259	·161386	·303	·200922
·172	·090041	·216	·124810	·260	·162263	·304	·201841
·173	·090797	·217	·125634	·261	·163140	·305	·202761
·174	·091554	·218	·126459	·262	·164019	·306	·203683
·175	·092313	·219	·127285	·263	·164899	·307	·204605
·176	·093074	·220	·128113	·264	·165780	·308	·205527
·177	·093836	·221	·128942	·265	·166663	·309	·206451
·178	·094601	·222	·129773	·266	·167546	·310	·207376
·179	·095366	·223	·130605	·267	·168430	·311	·208301
·180	·096134	·224	·131438	·268	·169315	·312	·209227
·181	·096903	·225	·132272	·269	·170202	·313	·210154
·182	·097674	·226	·133108	·270	·171089	·314	·211082
·183	·098447	·227	·133945	·271	·171978	·315	·212011
·184	·099221	·228	·134784	·272	·172867	·316	·212940
·185	·099997	·229	·135624	·273	·173758	·317	·213871
·186	·100774	·230	·136465	·274	·174649	·318	·214802
·187	·101553	·231	·137307	·275	·175542	·319	·215733
·188	·102334	·232	·138150	·276	·176435	·320	·216666
·189	·103116	·233	·138995	·277	·177330	·321	·217599
·190	·103900	·234	·139841	·278	·178225	·322	·218533
·191	·104685	·235	·140688	·279	·179122	·323	·219468
·192	·105472	·236	·141537	·280	·180019	·324	·220404

TABLE OF THE AREAS OF THE SEGMENTS OF A CIRCLE, THE DIAMETER BEING UNITY (concluded).

$\frac{H}{D}$	Area	$\frac{H}{D}$	Area	$\frac{H}{D}$	Area	$\frac{H}{D}$	Area
·325	·221340	·369	·263213	·413	·306140	·457	·349752
·326	·222277	·370	·264178	·414	·307125	·458	·350748
·327	·223215	·371	·265144	·415	·308110	·459	·351745
·328	·224154	·372	·266111	·416	·309095	·460	·352742
·329	·225093	·373	·267078	·417	·310081	·461	·353739
·330	·226033	·374	·268045	·418	·311068	·462	·354736
·331	·226974	·375	·269013	·419	·312054	·463	·355732
·332	·227915	·376	·269982	·420	·313041	·464	·356730
·333	·228858	·377	·270951	·421	·314029	·465	·357727
·334	·229801	·378	·271920	·422	·315016	·466	·358725
·335	·230745	·379	·272890	·423	·316004	·467	·359723
·336	·231689	·380	·273861	·424	·316992	·468	·360721
·337	·232634	·381	·274832	·425	·317981	·469	·361719
·338	·233580	·382	·275803	·426	·318970	·470	·362717
·339	·234526	·383	·276775	·427	·319959	·471	·363715
·340	·235473	·384	·277748	·428	·320948	·472	·364713
·341	·236421	·385	·278721	·429	·321938	·473	·365712
·342	·237369	·386	·279694	·430	·322928	·474	·366710
·343	·238318	·387	·280668	·431	·323918	·475	·367709
·344	·239268	·388	·281642	·432	·324909	·476	·368708
·345	·240218	·389	·282617	·433	·325900	·477	·369707
·346	·241169	·390	·283592	·434	·326892	·478	·370706
·347	·242121	·391	·284568	·435	·327882	·479	·371705
·348	·243074	·392	·285544	·436	·328874	·480	·372704
·349	·244026	·393	·286521	·437	·329866	·481	·373703
·350	·244980	·394	·287498	·438	·330858	·482	·374702
·351	·245934	·395	·288476	·439	·331850	·483	·375702
·352	·246889	·396	·289453	·440	·332843	·484	·376702
·353	·247845	·397	·290432	·441	·333836	·485	·377701
·354	·248801	·398	·291411	·442	·334829	·486	·378701
·355	·249757	·399	·292390	·443	·335822	·487	·379700
·356	·250715	·400	·293369	·444	·336816	·488	·380700
·357	·251673	·401	·294349	·445	·337810	·489	·381699
·358	·252631	·402	·295330	·446	·338804	·490	·382699
·359	·253590	·403	·296311	·447	·339798	·491	·383699
·360	·254550	·404	·297292	·448	·340793	·492	·384699
·361	·255510	·405	·298273	·449	·341787	·493	·385699
·362	·256471	·406	·299255	·450	·342782	·494	·386699
·363	·257433	·407	·300238	·451	·343777	·495	·387699
·364	·258395	·408	·301220	·452	·344772	·496	·388699
·365	·259357	·409	·302203	·453	·345768	·497	·389699
·366	·260320	·410	·303187	·454	·346764	·498	·390699
·367	·261284	·411	·304171	·455	·347759	·499	·391699
·368	·262248	·412	·305155	·456	·348755	·500	·392699

TABLE OF SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, AN[D] RECIPROCALS OF ALL INTEGER NUMBERS FROM 1 TO 2200

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1	1	1	1·0000000	1·0000000	1·00000000
2	4	8	1·4142136	1·2599210	·50000000
3	9	27	1·7320508	1·4422496	·33333333
4	16	64	2·0000000	1·5874011	·25000000
5	25	125	2·2360680	1·7099759	·20000000
6	36	216	2·4494897	1·8171206	·16666666
7	49	343	2·6457513	1·9129312	·14285714
8	64	512	2·8284271	2·0000000	·12500000
9	81	729	3·0000000	2·0800837	·11111111
10	1 00	1 000	3·1622777	2·1544347	·10000000
11	1 21	1 331	3·3166248	2·2239801	·09090909
12	1 44	1 728	3·4641016	2·2894286	·08333333
13	1 69	2 197	3·6055513	2·3513347	·07692307
14	1 96	2 744	3·7416574	2·4101422	·07142857
15	2 25	3 375	3·8729833	2·4662121	·06666666
16	2 56	4 096	4·0000000	2·5198421	·06250000
17	2 89	4 913	4·1231056	2·5712816	·05882352
18	3 24	5 832	4·2426407	2·6207414	·05555555
19	3 61	6 859	4·3588989	2·6684016	·05263157
20	4 00	8 000	4·4721360	2·7144177	·05000000
21	4 41	9 261	4·5825757	2·7589243	·04761904
22	4 84	10 648	4·6904158	2·8020393	·04545454
23	5 29	12 167	4·7958315	2·8438670	·04347826
24	5 76	13 824	4·8989795	2·8844991	·04166666
25	6 25	15 625	5·0000000	2·9240177	·04000000
26	6 76	17 576	5·0990195	2·9624960	·03846153
27	7 29	19 683	5·1961524	3·0000000	·03703703
28	7 84	21 952	5·2915026	3·0365889	·03571428
29	8 41	24 389	5·3851648	3·0723168	·03448275
30	9 00	27 000	5·4772256	3·1072325	·03333333
31	9 61	29 791	5·5677644	3·1413806	·03225806
32	10 24	32 768	5·6568542	3·1748021	·03125000
33	10 89	35 937	5·7445626	3·2075343	·03030303
34	11 56	39 304	5·8309519	3·2396118	·02941176
35	12 25	42 875	5·9160798	3·2710663	·02857142
36	12 96	46 656	6·0000000	3·3019272	·02777777
37	13 69	50 653	6·0827625	3·3322218	·02702702
38	14 44	54 872	6·1644140	3·3619754	·02631578
39	15 21	59 319	6·2449980	3·3912114	·02564102
40	16 00	64 000	6·3245553	3·4199519	·02500000
41	16 81	68 921	6·4031242	3·4482172	·02439024
42	17 64	74 088	6·4807407	3·4760266	·02380952
43	18 49	79 507	6·5574385	3·5033981	·02325581
44	19 36	85 184	6·6332496	3·5303483	·02272727
45	20 25	91 125	6·7082039	3·5568933	·02222222

No.	Square	Cube	Square Root	Cube Root	Reciprocal
46	21 16	97 336	6·7823300	3·5830479	·021739130
47	22 09	103 823	6·8556546	3·6088261	·021276600
48	23 04	110 592	6·9282032	3·6342411	·020833333
49	24 01	117 649	7·0000000	3·6593057	·020408163
50	25 00	125 000	7·0710678	3·6840314	·020000000
51	26 01	132 651	7·1414284	3·7084298	·019607843
52	27 04	140 608	7·2111026	3·7325111	·019230769
53	28 09	148 877	7·2801099	3·7562858	·018867925
54	29 16	157 464	7·3484692	3·7797631	·018518519
55	30 25	166 375	7·4161985	3·8029525	·018181818
56	31 36	175 616	7·4833148	3·8258624	·017857143
57	32 49	185 193	7·5498344	3·8485011	·017543860
58	33 64	195 112	7·6157731	3·8708766	·017241379
59	34 81	205 379	7·6811457	3·8929965	·016949153
60	36 00	216 000	7·7459667	3·9148676	·016666667
61	37 21	226 981	7·8102497	3·9364972	·016393443
62	38 44	238 328	7·8740079	3·9578915	·016129032
63	39 69	250 047	7·9372539	3·9790571	·015873016
64	40 96	262 144	8·0000000	4·0000000	·015625000
65	42 25	274 625	8·0622577	4·0207256	·015384615
66	43 56	287 496	8·1240384	4·0412401	·015151515
67	44 89	300 763	8·1853528	4·0615480	·014925373
68	46 24	314 432	8·2462113	4·0816551	·014705882
69	47 61	328 509	8·3066239	4·1015661	·014492754
70	49 00	343 000	8·3666003	4·1212853	·014285714
71	50 41	357 911	8·4261498	4·1408178	·014084507
72	51 84	373 248	8·4852814	4·1601676	·013888889
73	53 29	389 017	8·5440037	4·1793392	·013698630
74	54 76	405 224	8·6023253	4·1983364	·013513514
75	56 25	421 875	8·6602540	4·2171633	·013333333
76	57 76	438 976	8·7177979	4·2358236	·013157895
77	59 29	456 533	8·7749644	4·2543210	·012987013
78	60 84	474 552	8·8317609	4·2726586	·012820513
79	62 41	493 039	8·8881944	4·2908404	·012658228
80	64 00	512 000	8·9442719	4·3088695	·012500000
81	65 61	531 441	9·0000000	4·3267487	·012345679
82	67 24	551 368	9·0553851	4·3444815	·012195122
83	68 89	571 787	9·1104336	4·3620707	·012048193
84	70 56	592 704	9·1651514	4·3795191	·011904762
85	72 25	614 125	9·2195445	4·3968296	·011764706
86	73 96	636 056	9·2736185	4·4140049	·011627907
87	75 69	658 503	9·3273791	4·4310476	·011494253
88	77 44	681 472	9·3808315	4·4479602	·011363636
89	79 21	704 969	9·4339811	4·4647451	·011235955
90	81 00	729 000	9·4868330	4·4814047	·011111111
91	82 81	753 571	9·5393920	4·4979414	·010989011
92	84 64	778 688	9·5916630	4·5143574	·010869565
93	86 49	804 357	9·6436508	4·5306549	·010752688
94	88 36	830 584	9·6953597	4·5468359	·010638298

No.	Square	Cube	Square Root	Cube Root	Reciprocal
95	90 25	857 375	9·7467943	4·5629026	·010526316
96	92 16	884 736	9·7979590	4·5788570	·010416667
97	94 09	912 673	9·8488578	4·5947009	·010309278
98	96 04	941 192	9·8994949	4·6104363	·010204082
99	98 01	970 299	9·9498744	4·6260650	·010101010
100	1 00 00	1 000 000	10·0000000	4·6415888	·010000000
101	1 02 01	1 030 301	10·0498756	4·6570095	·009900990
102	1 04 04	1 061 208	10·0995049	4·6723287	·009803922
103	1 06 09	1 092 727	10·1488916	4·6875482	·009708738
104	1 08 16	1 124 864	10·1980390	4·7026694	·009615385
105	1 10 25	1 157 625	10·2469508	4·7176940	·009523810
106	1 12 36	1 191 016	10·2956301	4·7326235	·009433962
107	1 14 49	1 225 043	10·3440804	4·7474594	·009345794
108	1 16 64	1 259 712	10·3923048	4·7622032	·009259259
109	1 18 81	1 295 029	10·4403065	4·7768562	·009174312
110	1 21 00	1 331 000	10·4880885	4·7914199	·009090909
111	1 23 21	1 367 631	10·5356538	4·8058955	·009009009
112	1 25 44	1 404 928	10·5830052	4·8202845	·008928571
113	1 27 69	1 442 897	10·6301458	4·8345881	·008849558
114	1 29 96	1 481 544	10·6770783	4·8488076	·008771930
115	1 32 25	1 520 875	10·7238053	4·8629442	·008695652
116	1 34 56	1 560 896	10·7703296	4·8769990	·008620690
117	1 36 89	1 601 613	10·8166538	4·8909732	·008547009
118	1 39 24	1 643 032	10·8627805	4·9048681	·008474576
119	1 41 61	1 685 159	10·9087121	4·9186847	·008403361
120	1 44 00	1 728 000	10·9544512	4·9324242	·008333333
121	1 46 41	1 771 561	11·0000000	4·9460874	·008264463
122	1 48 84	1 815 848	11·0453610	4·9596757	·008196721
123	1 51 29	1 860 867	11·0905365	4·9731898	·008130081
124	1 53 76	1 906 624	11·1355287	4·9866310	·008064516
125	1 56 25	1 953 125	11·1803399	5·0000000	·008000000
126	1 58 76	2 000 376	11·2249722	5·0132979	·007936508
127	1 61 29	2 048 383	11·2694277	5·0265257	·007874016
128	1 63 84	2 097 152	11·3137085	5·0396842	·007812500
129	1 66 41	2 146 689	11·3578167	5·0527743	·007751938
130	1 69 00	2 197 000	11·4017543	5·0657970	·007692308
131	1 71 61	2 248 091	11·4455231	5·0787531	·007633588
132	1 74 24	2 299 968	11·4891253	5·0916434	·007575758
133	1 76 89	2 352 637	11·5325626	5·1044687	·007518797
134	1 79 56	2 406 104	11·5758369	5·1172299	·007462687
135	1 82 25	2 460 375	11·6189500	5·1299278	·007407407
136	1 84 96	2 515 456	11·6619038	5·1425632	·007352941
137	1 87 69	2 571 353	11·7046999	5·1551367	·007299270
138	1 90 44	2 628 072	11·7473401	5·1676493	·007246377
139	1 93 21	2 685 619	11·7898261	5·1801015	·007194245
140	1 96 00	2 744 000	11·8321596	5·1924941	·007142857
141	1 98 81	2 803 221	11·8743422	5·2048279	·007092199
142	2 01 64	2 863 288	11·9163753	5·2171034	·007042254
143	2 04 49	2 924 207	11·9582607	5·2293215	·006993007

No.	Square	Cube	Square Root	Cube Root	Reciprocal
144	2 07 36	2 985 984	12·0000000	5·2414828	·006944444
145	2 10 25	3 048 625	12·0415946	5·2535879	·006896552
146	2 13 16	3 112 136	12·0830460	5·2656374	·006849315
147	2 16 09	3 176 523	12·1243557	5·2776321	·006802721
148	2 19 04	3 241 792	12·1655251	5·2895725	·006756757
149	2 22 01	3 307 949	12·2065556	5·3014592	·006711409
150	2 25 00	3 375 000	12·2474487	5·3132928	·006666667
151	2 28 01	3 442 951	12·2882057	5·3250740	·006622517
152	2 31 04	3 511 808	12·3288280	5·3368033	·006578947
153	2 34 09	3 581 577	12·3693169	5·3484812	·006535948
154	2 37 16	3 652 264	12·4096736	5·3601084	·006493506
155	2 40 25	3 723 875	12·4498996	5·3716854	·006451613
156	2 43 36	3 796 416	12·4899960	5·3832126	·006410256
157	2 46 49	3 869 893	12·5299641	5·3946907	·006369427
158	2 49 64	3 944 312	12·5698051	5·4061202	·006329114
159	2 52 81	4 019 679	12·6095202	5·4175015	·006289308
160	2 56 00	4 096 000	12·6491106	5·4288352	·006250000
161	2 59 21	4 173 281	12·6885775	5·4401218	·006211180
162	2 62 44	4 251 528	12·7279221	5·4513618	·006172840
163	2 65 69	4 330 747	12·7671453	5·4625556	·006134969
164	2 68 96	4 410 944	12·8062485	5·4737037	·006097561
165	2 72 25	4 492 125	12·8452326	5·4848066	·006060606
166	2 75 56	4 574 296	12·8840987	5·4958647	·006024096
167	2 78 89	4 657 463	12·9228480	5·5068784	·005988024
168	2 82 24	4 741 632	12·9614814	5·5178484	·005952381
169	2 85 61	4 826 809	13·0000000	5·5287748	·005917160
170	2 89 00	4 913 000	13·0384048	5·5396583	·005882353
171	2 92 41	5 000 211	13·0766968	5·5504991	·005847953
172	2 95 84	5 088 448	13·1148770	5·5612978	·005813953
173	2 99 29	5 177 717	13·1529464	5·5720546	·005780347
174	3 02 76	5 268 024	13·1909060	5·5827702	·005747126
175	3 06 25	5 359 375	13·2287566	5·5934447	·005714286
176	3 09 76	5 451 776	13·2664992	5·6040787	·005681818
177	3 13 29	5 545 233	13·3041347	5·6146724	·005649718
178	3 16 84	5 639 752	13·3416641	5·6252263	·005617978
179	3 20 41	5 735 339	13·3790882	5·6357408	·005586592
180	3 24 00	5 832 000	13·4164079	5·6462162	·005555556
181	3 27 61	5 929 741	13·4536240	5·6566528	·005524862
182	3 31 24	6 028 568	13·4907376	5·6670511	·005494505
183	3 34 89	6 128 487	13·5277493	5·6774114	·005464481
184	3 38 56	6 229 504	13·5646600	5·6877340	·005434783
185	3 42 25	6 331 625	13·6014705	5·6980192	·005405405
186	3 45 96	6 434 856	13·6381817	5·7082675	·005376344
187	3 49 69	6 539 203	13·6747943	5·7184791	·005347594
188	3 53 44	6 644 672	13·7113092	5·7286543	·005319149
189	3 57 21	6 751 269	13·7477271	5·7387936	·005291005
190	3 61 00	6 859 000	13·7840488	5·7488971	·005263158
191	3 64 81	6 967 871	13·8202750	5·7589652	·005235602
192	3 68 64	7 077 888	13·8564065	5·7689982	·005208333

No.	Square	Cube	Square Root	Cube Root	Reciprocal
193	3 72 49	7 189 057	13·8924440	5·7789966	·005181347
194	3 76 36	7 301 384	13·9283883	5·7889604	·005154639
195	3 80 25	7 414 875	13·9642400	5·7988900	·005128205
196	3 84 16	7 529 536	14·0000000	5·8087857	·005102041
197	3 88 09	7 645 373	14·0356688	5·8186479	·005076142
198	3 92 04	7 762 392	14·0712473	5·8284767	·005050505
199	3 96 01	7 880 599	14·1067360	5·8382725	·005025126
200	4 00 00	8 000 000	14·1421356	5·8480355	·005000000
201	4 04 01	8 120 601	14·1774469	5·8577660	·004975124
202	4 08 04	8 242 408	14·2126704	5·8674643	·004950495
203	4 12 09	8 365 427	14·2478068	5·8771307	·004926108
204	4 16 16	8 489 664	14·2828569	5·8867653	·004901961
205	4 20 25	8 615 125	14·3178211	5·8963685	·004878049
206	4 24 36	8 741 816	14·3527001	5·9059406	·004854369
207	4 28 49	8 869 743	14·3874946	5·9154817	·004830918
208	4 32 64	8 998 912	14·4222051	5·9249921	·004807692
209	4 36 81	9 129 329	14·4568323	5·9344721	·004784689
210	4 41 00	9 261 000	14·4913767	5·9439220	·004761905
211	4 45 21	9 393 931	14·5258390	5·9533418	·004739336
212	4 49 44	9 528 128	14·5602198	5·9627320	·004716981
213	4 53 69	9 663 597	14·5945195	5·9720926	·004694836
214	4 57 96	9 800 344	14·6287388	5·9814240	·004672897
215	4 62 25	9 938 375	14·6628783	5·9907264	·004651163
216	4 66 56	10 077 696	14·6969385	6·0000000	·004629630
217	4 70 89	10 218 313	14·7309199	6·0092450	·004608295
218	4 75 24	10 360 232	14·7648231	6·0184617	·004587156
219	4 79 61	10 503 459	14·7986486	6·0276502	·004566210
220	4 84 00	10 648 000	14·8323970	6·0368107	·004545455
221	4 88 41	10 793 861	14·8660687	6·0459435	·004524887
222	4 92 84	10 941 048	14·8996644	6·0550489	·004504505
223	4 97 29	11 089 567	14·9331845	6·0641270	·004484305
224	5 01 76	11 239 424	14·9666295	6·0731779	·004464286
225	5 06 25	11 390 625	15·0000000	6·0822020	·004444444
226	5 10 76	11 543 176	15·0332964	6·0911994	·004424779
227	5 15 29	11 697 083	15·0665192	6·1001702	·004405286
228	5 19 84	11 852 352	15·0996689	6·1091147	·004385965
229	5 24 41	12 008 989	15·1327460	6·1180332	·004366812
230	5 29 00	12 167 000	15·1657509	6·1269257	·004347826
231	5 33 61	12 326 391	15·1986842	6·1357924	·004329004
232	5 38 24	12 487 168	15·2315462	6·1446337	·004310345
233	5 42 89	12 649 337	15·2643375	6·1534495	·004291845
234	5 47 56	12 812 904	15·2970585	6·1622401	·004273504
235	5 52 25	12 977 875	15·3297097	6·1710058	·004255319
236	5 56 96	13 144 256	15·3622915	6·1797466	·004237288
237	5 61 69	13 312 053	15·3948043	6·1884628	·004219409
238	5 66 44	13 481 272	15·4272486	6·1971544	·004201681
239	5 71 21	13 651 919	15·4596248	6·2058218	·004184100
240	5 76 00	13 824 000	15·4919334	6·2144650	·004166667
241	5 80 81	13 997 521	15·5241747	6·2230843	·004149378

No.	Square	Cube	Square Root	Cube Root	Reciprocal
242	5 85 64	14 172 488	15·5563492	6·2316797	·004132231
243	5 90 49	14 348 907	15·5884573	6·2402515	·004115226
244	5 95 36	14 526 784	15·6204994	6·2487998	·004098361
245	6 00 25	14 706 125	15·6524758	6·2573248	·004081633
246	6 05 16	14 886 936	15·6843871	6·2658266	·004065041
247	6 10 09	15 069 223	15·7162336	6·2743054	·004048583
248	6 15 04	15 252 992	15·7480157	6·2827613	·004032258
249	6 20 01	15 438 249	15·7797338	6·2911946	·004016064
250	6 25 00	15 625 000	15·8113883	6·2996053	·004000000
251	6 30 01	15 813 251	15·8429795	6·3079935	·003984064
252	6 35 04	16 003 008	15·8745079	6·3163596	·003968254
253	6 40 09	16 194 277	15·9059737	6·3247035	·003952569
254	6 45 16	16 387 064	15·9373775	6·3330256	·003937008
255	6 50 25	16 581 375	15·9687194	6·3413257	·003921569
256	6 55 36	16 777 216	16·0000000	6·3496042	·003906250
257	6 60 49	16 974 593	16·0312195	6·3578611	·003891051
258	6 65 64	17 173 512	16·0623784	6·3660968	·003875969
259	6 70 81	17 373 979	16·0934769	6·3743111	·003861004
260	6 76 00	17 576 000	16·1245155	6·3825043	·003846154
261	6 81 21	17 779 581	16·1554944	6·3906765	·003831418
262	6 86 44	17 984 728	16·1864141	6·3988279	·003816794
263	6 91 69	18 191 447	16·2172747	6·4069585	·003802281
264	6 96 96	18 399 744	16·2480768	6·4150687	·003787879
265	7 02 25	18 609 625	16·2788206	6·4231583	·003773585
266	7 07 56	18 821 096	16·3095064	6·4312276	·003759398
267	7 12 89	19 034 163	16·3401346	6·4392767	·003745318
268	7 18 24	19 248 832	16·3707055	6·4473057	·003731343
269	7 23 61	19 465 109	16·4012195	6·4553148	·003717472
270	7 29 00	19 683 000	16·4316767	6·4633041	·003703704
271	7 34 41	19 902 511	16·4620776	6·4712736	·003690037
272	7 39 84	20 123 648	16·4924225	6·4792236	·003676471
273	7 45 29	20 346 417	16·5227116	6·4871541	·003663004
274	7 50 76	20 570 824	16·5529454	6·4950653	·003649635
275	7 56 25	20 796 875	16·5831240	6·5029572	·003636364
276	7 61 76	21 024 576	16·6132477	6·5108300	·003623188
277	7 67 29	21 253 933	16·6433170	6·5186839	·003610108
278	7 72 84	21 484 952	16·6733320	6·5265189	·003597122
279	7 78 41	21 717 639	16·7032931	6·5343351	·003584229
280	7 84 00	21 952 000	16·7332005	6·5421326	·003571429
281	7 89 61	22 188 041	16·7630546	6·5499116	·003558719
282	7 95 24	22 425 768	16·7928556	6·5576722	·003546099
283	8 00 89	22 665 187	16·8226038	6·5654144	·003533569
284	8 06 56	22 906 304	16·8522995	6·5731385	·003521127
285	8 12 25	23 149 125	16·8819430	6·5808443	·003508772
286	8 17 96	23 393 656	16·9115345	6·5885323	·003496503
287	8 23 69	23 639 903	16·9410743	6·5962023	·003484321
288	8 29 44	23 887 872	16·9705627	6·6038545	·003472222
289	8 35 21	24 137 569	17·0000000	6·6114890	·003460208
290	8 41 00	24 389 000	17·0293864	6·6191060	·003448276

No.	Square	Cube	Square Root	Cube Root	Reciprocal
291	8 46 81	24 642 171	17·0587221	6·6267054	·003436426
292	8 52 64	24 897 088	17·0880075	6·6342874	·003424658
293	8 58 49	25 153 757	17·1172428	6·6418522	·003412969
294	8 64 36	25 412 184	17·1464282	6·6493998	·003401361
295	8 70 25	25 672 375	17·1755640	6·6569302	·003389831
296	8 76 16	25 934 336	17·2046505	6·6644437	·003378378
297	8 82 09	26 198 073	17·2336879	6·6719403	·003367003
298	8 88 04	26 463 592	17·2626765	6·6794200	·003355705
299	8 94 01	26 730 899	17·2916165	6·6868831	·003344482
300	9 00 00	27 000 000	17·3205081	6·6943295	·003333333
301	9 06 01	27 270 901	17·3493516	6·7017593	·003322259
302	9 12 04	27 543 608	17·3781472	6·7091729	·003311258
303	9 18 09	27 818 127	17·4068952	6·7165700	·003300330
304	9 24 16	28 094 464	17·4355958	6·7239508	·003289474
305	9 30 25	28 372 625	17·4642492	6·7313155	·003278689
306	9 36 36	28 652 616	17·4928557	6·7386641	·003267974
307	9 42 49	28 934 443	17·5214155	6·7459967	·003257329
308	9 48 64	29 218 112	17·5499288	6·7533134	·003246753
309	9 54 81	29 503 629	17·5783958	6·7606143	·003236246
310	9 61 00	29 791 000	17·6068169	6·7678995	·003225806
311	9 67 21	30 080 231	17·6351921	6·7751690	·003215434
312	9 73 44	30 371 328	17·6635217	6·7824229	·003205128
313	9 79 69	30 664 297	17·6918060	6·7896613	·003194888
314	9 85 96	30 959 144	17·7200451	6·7968844	·003184713
315	9 92 25	31 255 875	17·7482393	6·8040921	·003174603
316	9 98 56	31 554 496	17·7763888	6·8112847	·003164557
317	10 04 89	31 855 013	17·8044938	6·8184620	·003154574
318	10 11 24	32 157 432	17·8325545	6·8256242	·003144654
319	10 17 61	32 461 759	17·8605711	6·8327714	·003134796
320	10 24 00	32 768 000	17·8885438	6·8399037	·003125000
321	10 30 41	33 076 161	17·9164729	6·8470213	·003115265
322	10 36 84	33 386 248	17·9443584	6·8541240	·003105590
323	10 43 29	33 698 267	17·9722008	6·8612120	·003095975
324	10 49 76	34 012 224	18·0000000	6·8682855	·003086420
325	10 56 25	34 328 125	18·0277564	6·8753443	·003076923
326	10 62 76	34 645 976	18·0554701	6·8823888	·003067485
327	10 69 29	34 965 783	18·0831413	6·8894188	·003058104
328	10 75 84	35 287 552	18·1107703	6·8964345	·003048780
329	10 82 41	35 611 289	18·1383571	6·9034359	·003039514
330	10 89 00	35 937 000	18·1659021	6·9104232	·003030303
331	10 95 61	36 264 691	18·1934054	6·9173964	·003021148
332	11 02 24	36 594 368	18·2208672	6·9243556	·003012048
333	11 08 89	36 926 037	18·2482876	6·9313008	·003003003
334	11 15 56	37 259 704	18·2756669	6·9382321	·002994012
335	11 22 25	37 595 375	18·3030052	6·9451496	·002985075
336	11 28 96	37 933 056	18·3303028	6·9520533	·002976190
337	11 35 69	38 272 753	18·3575598	6·9589434	·002967359
338	11 42 44	38 614 472	18·3847763	6·9658198	·002958580
339	11 49 21	38 958 219	18·4119526	6·9726826	·002949853

No.	Square	Cube	Square Root	Cube Root	Reciprocal
340	11 56 00	39 304 000	18·4390889	6·9795321	·002941176
341	11 62 81	39 651 821	18·4661853	6·9863681	·002932551
342	11 69 64	40 001 688	18·4932420	6·9931906	·002923977
343	11 76 49	40 353 607	18·5202592	7·0000000	·002915452
344	11 83 36	40 707 584	18·5472370	7·0067962	·002906977
345	11 90 25	41 063 625	18·5741756	7·0135791	·002898551
346	11 97 16	41 421 736	18·6010752	7·0203490	·002890173
347	12 04 09	41 781 923	18·6279360	7·0271058	·002881844
348	12 11 04	42 144 192	18·6547581	7·0338497	·002873563
349	12 18 01	42 508 549	18·6815147	7·0405806	·002865330
350	12 25 00	42 875 000	18·7082869	7·0472987	·002857143
351	12 32 01	43 243 551	18·7349940	7·0540041	·002849003
352	12 39 04	43 614 208	18·7616630	7·0606967	·002840909
353	12 46 09	43 986 977	18·7882942	7·0673767	·002832861
354	12 53 16	44 361 864	18·8148877	7·0740440	·002824859
355	12 60 25	44 738 875	18·8414437	7·0806988	·002816901
356	12 67 36	45 118 016	18·8679623	7·0873411	·002808989
357	12 74 49	45 499 293	18·8944436	7·0939709	·002801120
358	12 81 64	45 882 712	18·9208879	7·1005885	·002793296
359	12 88 81	46 268 279	18·9472953	7·1071937	·002785515
360	12 96 00	46 656 000	18·9736660	7·1137866	·002777778
361	13 03 21	47 045 881	19·0000000	7·1203674	·002770083
362	13 10 44	47 437 928	19·0262976	7·1269360	·002762431
363	13 17 69	47 832 147	19·0525589	7·1334925	·002754821
364	13 24 96	48 228 544	19·0787840	7·1400370	·002747253
365	13 32 25	48 627 125	19·1049732	7·1465695	·002739726
366	13 39 56	49 027 896	19·1311265	7·1530901	·002732240
367	13 46 89	49 430 863	19·1572441	7·1595988	·002724796
368	13 54 24	49 836 032	19·1833261	7·1660957	·002717391
369	13 61 61	50 243 409	19·2093727	7·1725809	·002710027
370	13 69 00	50 653 000	19·2353841	7·1790544	·002702703
371	13 76 41	51 064 811	19·2613603	7·1855162	·002695418
372	13 83 84	51 478 848	19·2873015	7·1919663	·002688172
373	13 91 29	51 895 117	19·3132079	7·1984050	·002680965
374	13 98 76	52 313 624	19·3390796	7·2048322	·002673797
375	14 06 25	52 734 375	19·3649167	7·2112479	·002666667
376	14 13 76	53 157 376	19·3907194	7·2176522	·002659574
377	14 21 29	53 582 633	19·4164878	7·2240450	·002652520
378	14 28 84	54 010 152	19·4422221	7·2304268	·002645503
379	14 36 41	54 439 939	19·4679223	7·2367972	·002638522
380	14 44 00	54 872 000	19·4935887	7·2431565	·002631579
381	14 51 61	55 306 341	19·5192213	7·2495045	·002624672
382	14 59 24	55 742 968	19·5448203	7·2558415	·002617801
383	14 66 89	56 181 887	19·5703858	7·2621675	·002610966
384	14 74 56	56 623 104	19·5959179	7·2684824	·002604167
385	14 82 25	57 066 625	19·6214169	7·2747864	·002597403
386	14 89 96	57 512 456	19·6468827	7·2810794	·002590674
387	14 97 69	57 960 603	19·6723156	7·2873617	·002583979
388	15 05 44	58 411 072	19·6977156	7·2936330	·002577320

No.	Square	Cube	Square Root	Cube Root	Reciprocal
389	15 13 21	58 863 869	19·7230829	7·2998936	·002570694
390	15 21 00	59 319 000	19·7484177	7·3061436	·002564103
391	15 28 81	59 776 471	19·7737199	7·3123828	·002557545
392	15 36 64	60 236 288	19·7989899	7·3186114	·002551020
393	15 44 49	60 698 457	19·8242276	7·3248295	·002544529
394	15 52 36	61 162 984	19·8494332	7·3310369	·002538071
395	15 60 25	61 629 875	19·8746069	7·3372339	·002531646
396	15 68 16	62 099 136	19·8997487	7·3434205	·002525253
397	15 76 09	62 570 773	19·9248588	7·3495966	·002518892
398	15 84 04	63 044 792	19·9499373	7·3557624	·002512563
399	15 92 01	63 521 199	19·9749844	7·3619178	·002506266
400	16 00 00	64 000 000	20·0000000	7·3680630	·002500000
401	16 08 01	64 481 201	20·0249844	7·3741979	·002493766
402	16 16 04	64 964 808	20·0499377	7·3803227	·002487562
403	16 24 09	65 450 827	20·0748599	7·3864373	·002481390
404	16 32 16	65 939 264	20·0997512	7·3925418	·002475248
405	16 40 25	66 430 125	20·1246118	7·3986363	·002469136
406	16 48 36	66 923 416	20·1494417	7·4047206	·002463054
407	16 56 49	67 419 143	20·1742410	7·4107950	·002457002
408	16 64 64	67 917 312	20·1990099	7·4168595	·002450980
409	16 72 81	68 417 929	20·2237484	7·4229142	·002444988
410	16 81 00	68 921 000	20·2484567	7·4289589	·002439024
411	16 89 21	69 426 531	20·2731349	7·4349938	·002433090
412	16 97 44	69 934 528	20·2977831	7·4410189	·002427184
413	17 05 69	70 444 997	20·3224014	7·4470342	·002421308
414	17 13 96	70 957 944	20·3469899	7·4530399	·002415459
415	17 22 25	71 473 375	20·3715488	7·4590359	·002409639
416	17 30 56	71 991 296	20·3960781	7·4650223	·002403846
417	17 38 89	72 511 713	20·4205779	7·4709991	·002398082
418	17 47 24	73 034 632	20·4450483	7·4769664	·002392344
419	17 55 61	73 560 059	20·4694895	7·4829242	·002386635
420	17 64 00	74 088 000	20·4939015	7·4888724	·002380952
421	17 72 41	74 618 461	20·5182845	7·4948113	·002375297
422	17 80 84	75 151 448	20·5426386	7·5007406	·002369668
423	17 89 29	75 686 967	20·5669638	7·5066607	·002364066
424	17 97 76	76 225 024	20·5912603	7·5125715	·002358491
425	18 06 25	76 765 625	20·6155281	7·5184730	·002352941
426	18 14 76	77 308 776	20·6397674	7·5243652	·002347418
427	18 23 29	77 854 483	20·6639783	7·5302482	·002341920
428	18 31 84	78 402 752	20·6881609	7·5361221	·002336449
429	18 40 41	78 953 589	20·7123152	7·5419867	·002331002
430	18 49 00	79 507 000	20·7364414	7·5478423	·002325581
431	18 57 61	80 062 991	20·7605395	7·5536888	·002320186
432	18 66 24	80 621 568	20·7846097	7·5595263	·002314815
433	18 74 89	81 182 737	20·8086520	7·5653548	·002309469
434	18 83 56	81 746 504	20·8326667	7·5711743	·002304147
435	18 92 25	82 312 875	20·8566536	7·5769849	·002298851
436	19 00 96	82 881 856	20·8806130	7·5827865	·002293578
437	19 09 69	83 453 453	20·9045450	7·5885793	·002288330

No.	Square	Cube	Square Root	Cube Root	Reciprocal
438	19 18 44	84 027 672	20·9284495	7·5943633	·002283105
439	19 27 21	84 604 519	20·9523268	7·6001385	·002277904
440	19 36 00	85 184 000	20·9761770	7·6059049	·002272727
441	19 44 81	85 766 121	21·0000000	7·6116626	·002267574
442	19 53 64	86 350 888	21·0237960	7·6174116	·002262443
443	19 62 49	86 938 307	21·0475652	7·6231519	·002257336
444	19 71 36	87 528 384	21·0713075	7·6288837	·002252252
445	19 80 25	88 121 125	21·0950231	7·6346067	·002247191
446	19 89 16	88 716 536	21·1187121	7·6403213	·002242152
447	19 98 09	89 314 623	21·1423745	7·6460272	·002237136
448	20 07 04	89 915 392	21·1660105	7·6517247	·002232143
449	20 16 01	90 518 849	21·1896201	7·6574138	·002227171
450	20 25 00	91 125 000	21·2132034	7·6630943	·002222222
451	20 34 01	91 733 851	21·2367606	7·6687665	·002217295
452	20 43 04	92 345 408	21·2602916	7·6744303	·002212389
453	20 52 09	92 959 677	21·2837967	7·6800857	·002207506
454	20 61 16	93 576 664	21·3072758	7·6857328	·002202643
455	20 70 25	94 196 375	21·3307290	7·6913717	·002197802
456	20 79 36	94 818 816	21·3541565	7·6970023	·002192982
457	20 88 49	95 443 993	21·3775583	7·7026246	·002188184
458	20 97 64	96 071 912	21·4009346	7·7082388	·002183406
459	21 06 81	96 702 579	21·4242853	7·7138448	·002178649
460	21 16 00	97 336 000	21·4476106	7·7194426	·002173913
461	21 25 21	97 972 181	21·4709106	7·7250325	·002169197
462	21 34 44	98 611 128	21·4941853	7·7306141	·002164502
463	21 43 69	99 252 847	21·5174348	7·7361877	·002159827
464	21 52 96	99 897 344	21·5406592	7·7417532	·002155172
465	21 62 25	100 544 625	21·5638587	7·7473109	·002150538
466	21 71 56	101 194 696	21·5870331	7·7528606	·002145923
467	21 80 89	101 847 563	21·6101828	7·7584023	·002141328
468	21 90 24	102 503 232	21·6333077	7·7639361	·002136752
469	21 99 61	103 161 709	21·6564078	7·7694620	·002132196
470	22 09 00	103 823 000	21·6794834	7·7749801	·002127660
471	22 18 41	104 487 111	21·7025344	7·7804904	·002123142
472	22 27 84	105 154 048	21·7255610	7·7859928	·002118644
473	22 37 29	105 823 817	21·7485632	7·7914875	·002114165
474	22 46 76	106 496 424	21·7715411	7·7969745	·002109705
475	22 56 25	107 171 875	21·7944947	7·8024538	·002105263
476	22 65 76	107 850 176	21·8174242	7·8079254	·002100840
477	22 75 29	108 531 333	21·8403297	7·8133892	·002096436
478	22 84 84	109 215 352	21·8632111	7·8188456	·002092050
479	25 94 41	109 902 239	21·8860686	7·8242942	·002087683
480	23 04 00	110 592 000	21·9089023	7·8297353	·002083333
481	23 13 61	111 284 641	21·9317122	7·8351688	·002079002
482	23 23 24	111 980 168	21·9544984	7·8405949	·002074689
483	23 32 89	112 678 587	21·9772610	7·8460134	·002070393
484	23 42 56	113 379 904	22·0000000	7·8514244	·002066116
485	23 52 25	114 084 125	22·0227155	7·8568281	·002061856
486	23 61 96	114 791 256	22·0454077	7·8622242	002057613

No.	Square	Cube	Square Root	Cube Root	Reciprocal
487	23 71 69	115 501 303	22·0680765	7·8676130	·002053388
488	23 81 44	116 214 272	22·0907220	7·8729944	·002049180
489	23 91 21	116 930 169	22·1133444	7·8783684	·002044990
490	24 01 00	117 649 000	22·1359436	7·8837352	·002040816
491	24 10 81	118 370 771	22·1585198	7·8890946	·002036660
492	24 20 64	119 095 488	22·1810730	7·8944468	·002032520
493	24 30 49	119 823 157	22·2036033	7·8997917	·002028398
494	24 40 36	120 553 784	22·2261108	7·9051294	·002024291
495	24 50 25	121 287 375	22·2485955	7·9104599	·002020202
496	24 60 16	122 023 936	22·2710575	7·9157832	·002016129
497	24 70 09	122 763 473	22·2934968	7·9210994	·002012072
498	24 80 04	123 505 992	22·3159136	7·9264085	·002008032
499	24 90 01	124 251 499	22·3383079	7·9317104	·002004008
500	25 00 00	125 000 000	22·3606798	7·9370053	·002000000
501	25 10 01	125 751 501	22·3830293	7·9422931	·001996008
502	25 20 04	126 506 008	22·4053565	7·9475739	·001992032
503	25 30 09	127 263 527	22·4276615	7·9528477	·001988072
504	25 40 16	128 024 064	22·4499443	7·9581144	·001984127
505	25 50 25	128 787 625	22·4722051	7·9633743	·001980198
506	25 60 36	129 554 216	22·4944438	7·9686271	·001976285
507	25 70 49	130 323 843	22·5166605	7·9738731	·001972387
508	25 80 64	131 096 512	22·5388553	7·9791122	·001968504
509	25 90 81	131 872 229	22·5610283	7·9843444	·001964637
510	26 01 00	132 651 000	22·5831796	7·9895697	·001960784
511	26 11 21	133 432 831	22·6053091	7·9947883	·001956947
512	26 21 44	134 217 728	22·6274170	8·0000000	·001953125
513	26 31 69	135 005 697	22·6495033	8·0052049	·001949318
514	26 41 96	135 796 744	22·6715681	8·0104032	·001945525
515	26 52 25	136 590 875	22·6936114	8·0155946	·001941748
516	26 62 56	137 388 096	22·7156334	8·0207794	·001937984
517	26 72 89	138 188 413	22·7376340	8·0259574	·001934236
518	26 83 24	138 991 832	22·7596134	8·0311287	·001930502
519	26 93 61	139 798 359	22·7815715	8·0362935	·001926782
520	27 04 00	140 608 000	22·8035085	8·0414515	·001923077
521	27 14 41	141 420 761	22·8254244	8·0466030	·001919386
522	27 24 84	142 236 648	22·8473193	8·0517479	·001915709
523	27 35 29	143 055 667	22·8691933	8·0568862	·001912046
524	27 45 76	143 877 824	22·8910463	8·0620180	·001908397
525	27 56 25	144 703 125	22·9128785	8·0671432	·001904762
526	27 66 76	145 531 576	22·9346899	8·0722620	·001901141
527	27 77 29	146 363 183	22·9564806	8·0773743	·001897533
528	27 87 84	147 197 952	22·9782506	8·0824800	·001893939
529	27 98 41	148 035 889	23·0000000	8·0875794	·001890359
530	28 09 00	148 877 000	23·0217289	8·0926723	·001886792
531	28 19 61	149 721 291	23·0434372	8·0977589	·001883239
532	28 30 24	150 568 768	23·0651252	8·1028390	·001879699
533	28 40 89	151 419 437	23·0867928	8·1079128	·001876173
534	28 51 56	152 273 304	23·1084400	8·1129803	·001872659
535	28 62 25	153 130 375	23·1300670	8·1180414	·001869159

No.	Square	Cube	Square Root	Cube Root	Reciprocal
536	28 72 96	153 990 656	23·1516738	8·1230962	·001865672
537	28 83 69	154 854 153	23·1732605	8·1281447	·001862197
538	28 94 44	155 720 872	23·1948270	8·1331870	·001858736
539	29 05 21	156 590 819	23·2163735	8·1382230	·001855288
540	29 16 00	157 464 000	23·2379001	8·1432529	·001851852
541	29 26 81	158 340 421	23·2594067	8·1482765	·001848429
542	29 37 64	159 220 088	23·2808935	8·1532939	·001845018
543	29 48 49	160 103 007	23·3023604	8·1583051	·001841621
544	29 59 36	160 989 184	23·3238076	8·1633102	·001838235
545	29 70 25	161 878 625	23·3452351	8·1683092	·001834862
546	29 81 16	162 771 336	23·3666429	8·1733020	·001831502
547	29 92 09	163 667 323	23·3880311	8·1782888	·001828154
548	30 03 04	164 566 592	23·4093998	8·1832695	·001824818
549	30 14 01	165 469 149	23·4307490	8·1882441	·001821494
550	30 25 00	166 375 000	23·4520788	8·1932127	·001818182
551	30 36 01	167 284 151	23·4733892	8·1981753	·001814882
552	30 47 04	168 196 608	23·4946802	8·2031319	·001811594
553	30 58 09	169 112 377	23·5159520	8·2080825	·001808318
554	30 69 16	170 031 464	23·5372046	8·2130271	·001805054
555	30 80 25	170 953 875	23·5584380	8·2179657	·001801802
556	30 91 36	171 879 616	23·5796522	8·2228985	·001798561
557	31 02 49	172 808 693	23·6008474	8·2278254	·001795332
558	31 13 64	173 741 112	23·6220236	8·2327463	·001792115
559	31 24 81	174 676 879	23·6431808	8·2376614	·001788909
560	31 36 00	175 616 000	23·6643191	8·2425706	·001785714
561	31 47 21	176 558 481	23·6854386	8·2474740	·001782531
562	31 58 44	177 504 328	23·7065392	8·2523715	·001779359
563	31 69 69	178 453 547	23·7276210	8·2572633	·001776199
564	31 80 96	179 406 144	23·7486842	8·2621492	·001773050
565	31 92 25	180 362 125	23·7697286	8·2670294	·001769912
566	32 03 56	181 321 496	23·7907545	8·2719039	·001766784
567	32 14 89	182 284 263	23·8117618	8·2767726	·001763668
568	32 26 24	183 250 432	23·8327506	8·2816355	·001760563
569	32 37 61	184 220 009	23·8537209	8·2864928	·001757469
570	32 49 00	185 193 000	23·8746728	8·2913444	·001754386
571	32 60 41	186 169 411	23·8956063	8·2961903	·001751313
572	32 71 84	187 149 248	23·9165215	8·3010304	·001748252
573	32 83 29	188 132 517	23·9374184	8·3058651	·001745201
574	32 94 76	189 119 224	23·9582971	8·3106941	·001742160
575	33 06 25	190 109 375	23·9791576	8·3155175	·001739130
576	33 17 76	191 102 976	24·0000000	8·3203353	·001736111
577	33 29 29	192 100 033	24·0208243	8·3251475	·001733102
578	33 40 84	193 100 552	24·0416306	8·3299542	·001730104
579	33 52 41	194 104 539	24·0624188	8·3347553	·001727116
580	33 64 00	195 112 000	24·0831891	8·3395509	·001724138
581	33 75 61	196 122 941	24·1039416	8·3443410	·001721170
582	33 87 24	197 137 368	24·1246762	8·3491256	·001718213
583	33 98 89	198 155 287	24·1453929	8·3539047	·001715266
584	34 10 56	199 176 704	24·1660919	8·3586784	·001712329

No.	Square	Cube	Square Root	Cube Root	Reciprocal
585	34 22 25	200 201 625	24·1867732	8·3634466	·001709402
586	34 33 96	201 230 056	24·2074369	8·3682095	·001706485
587	34 45 69	202 262 003	24·2280829	8·3729668	·001703578
588	34 57 44	203 297 472	24·2487113	8·3777188	·005700680
589	34 69 21	204 336 469	24·2693222	8·3824653	·001697793
590	34 81 00	205 379 000	24·2899156	8·3872065	·001694915
591	34 92 81	206 425 071	24·3104916	8·3919423	·001692047
592	35 04 64	207 474 688	24·3310501	8·3966729	·001689189
593	35 16 49	208 527 857	24·3515913	8·4013981	·001686341
594	35 28 36	209 584 584	24·3721152	8·4061180	·001683502
595	35 40 25	210 644 875	24·3926218	8·4108326	·001680672
596	35 52 16	211 708 736	24·4131112	8·4155419	·001677852
597	35 64 09	212 776 173	24·4335834	8·4202460	·001675042
598	35 76 04	213 847 192	24·4540385	8·4249448	·001672241
599	35 88 01	214 921 799	24·4744765	8·4296383	·001669449
600	36 00 00	216 000 000	24·4948974	8·4343267	·001666667
601	36 12 01	217 081 801	24·5153013	8·4390098	·001663894
602	36 24 04	218 167 208	24·5356883	8·4436877	·001661130
603	36 36 09	219 256 227	24·5560583	8·4483605	·001658375
604	36 48 16	220 348 864	24·5764115	8·4530281	·001655629
605	36 60 25	221 445 125	24·5967478	8·4576906	·001652893
606	36 72 36	222 545 016	24·6170673	8·4623479	·001650165
607	36 84 49	223 648 543	24·6373700	8·4670000	·001647446
608	36 96 64	224 755 712	24·6576560	8·4716471	·001644737
609	37 08 81	225 866 529	24·6779254	8·4762892	·001642036
610	37 21 00	226 981 000	24·6981781	8·4809261	·001639344
611	37 33 21	228 099 131	24·7184142	8·4855579	·001636661
612	37 45 44	229 220 928	24·7386338	8·4901848	·001633987
613	37 57 69	230 346 397	24·7588368	8·4948065	·001631321
614	37 69 96	231 475 544	24·7790234	8·4994233	·001628664
615	37 82 25	232 608 375	24·7991935	8·5040350	·001626016
616	37 94 56	233 744 896	24·8193473	8·5086417	·001623377
617	38 06 89	234 885 113	24·8394847	8·5132435	·001620746
618	38 19 24	236 029 032	24·8596058	8·5178403	·001618123
619	38 31 61	237 176 659	24·8797106	8·5224321	·001615509
620	38 44 00	238 328 000	24·8997992	8·5270189	·001612903
621	38 56 41	239 483 061	24·9198716	8·5316009	·001610306
622	38 68 84	240 641 848	24·9399278	8·5361780	·001607717
623	38 81 29	241 804 367	24·9599679	8·5407501	·001605136
624	38 93 76	242 970 624	24·9799920	8·5453173	·001602564
625	39 06 25	244 140 625	25·0000000	8·5498797	·001600000
626	39 18 76	245 314 376	25·0199920	8·5544372	·001597444
627	39 31 29	246 491 883	25·0399681	8·5589899	·001594896
628	39 43 84	247 673 152	25·0599282	8·5635377	·001592357
629	39 56 41	248 858 189	25·0798724	8·5680807	·001589825
630	39 69 00	250 047 000	25·0998008	8·5726189	·001587302
631	39 81 61	251 239 591	25·1197134	8·5771523	·001584786
632	39 94 24	252 435 968	25·1396102	8·5816809	·001582278
633	40 06 89	253 636 137	25·1594913	8·5862047	·001579779

No.	Square	Cube	Square Root	Cube Root	Reciprocal
634	40 19 56	254 840 104	25·1793566	8·5907238	·001577287
635	40 32 25	256 047 875	25·1992063	8·5952380	·001574803
636	40 44 96	257 259 456	25·2190404	8·5997476	·001572327
637	40 57 69	258 474 853	25·2388589	8·6042525	·001569859
638	40 70 44	259 694 072	25·2586619	8·6087526	·001567398
639	40 83 21	260 917 119	25·2784493	8·6132480	·001564945
640	40 96 00	262 144 000	25·2982213	8·6177388	·001562500
641	41 08 81	263 374 721	25·3179778	8·6222248	·001560062
642	41 21 64	264 609 288	25·3377189	8·6267063	·001557632
643	41 34 49	265 847 707	25·3574447	8·6311830	·001555210
644	41 47 36	267 089 984	25·3771551	8·6356551	·001552795
645	41 60 25	268 336 125	25·3968502	8·6401226	·001550388
646	41 73 16	269 586 136	25·4165301	8·6445855	·001547988
647	41 86 09	270 840 023	25·4361947	8·6490437	·001545595
648	41 99 04	272 097 792	25·4558441	8·6534974	·001543210
649	42 12 01	273 359 449	25·4754784	8·6579465	·001540832
650	42 25 00	274 625 000	25·4950976	8·6623911	·001538462
651	42 38 01	275 894 451	25·5147016	8·6668310	·001536098
652	42 51 04	277 167 808	25·5342907	8·6712665	·001533742
653	42 64 09	278 445 077	25·5538647	8·6756974	·001531394
654	42 77 16	279 726 264	25·5734237	8·6801237	·001529052
655	42 90 25	281 011 375	25·5929678	8·6845456	·001526718
656	43 03 36	282 300 416	25·6124969	8·6889630	·001524390
657	43 16 49	283 593 393	25·6320112	8·6933759	·001522070
658	43 29 64	284 890 312	25·6515107	8·6977843	·001519757
659	43 42 81	286 191 179	25·6709953	8·7021882	·001517451
660	43 56 00	287 496 000	25·6904652	8·7065877	·001515152
661	43 69 21	288 804 781	25·7099203	8·7109827	·001512859
662	43 82 44	290 117 528	25·7293607	8·7153734	·001510574
663	43 95 69	291 434 247	25·7487864	8·7197596	·001508296
664	44 08 96	292 754 944	25·7681975	8·7241414	·001506024
665	44 22 25	294 079 625	25·7875939	8·7285187	·001503759
666	44 35 56	295 408 296	25·8069758	8·7328918	·001501502
667	44 48 89	296 740 963	25·8263431	8·7372604	·001499250
668	44 62 24	298 077 632	25·8456960	8·7416246	·001497006
669	44 75 61	299 418 309	25·8650343	8·7459846	·001494768
670	44 89 00	300 763 000	25·8843582	8·7503401	·001492537
671	45 02 41	302 111 711	25·9036677	8·7546913	·001490313
672	45 15 84	303 464 448	25·9229628	8·7590383	·001488095
673	45 29 29	304 821 217	25·9422435	8·7633809	·001485884
674	45 42 76	306 182 024	25·9615100	8·7677192	·001483680
675	45 56 25	307 546 875	25·9807621	8·7720532	·001481481
676	45 69 76	308 915 776	26·0000000	8·7763830	·001479290
677	45 83 29	310 288 733	26·0192237	8·7807084	·001477105
678	45 96 84	311 665 752	26·0384331	8·7850296	·001474926
679	46 10 41	313 046 839	26·0576284	8·7893466	·001472754
680	46 24 00	314 432 000	26·0768096	8·7936593	·001470588
681	46 37 61	315 821 241	26·0959767	8·7979679	·001468429
682	46 51 24	317 214 568	26·1151297	8·8022721	·001466276

No.	Square	Cube	Square Root	Cube Root	Reciprocal
683	46 64 89	318 611 987	26·1342687	8·8065722	·001464129
684	46 78 56	320 013 504	26·1533937	8·8108681	·001461988
685	46 92 25	321 419 125	26·1725047	8·8151598	·001459854
686	47 05 96	322 828 856	26·1916017	8·8194474	·001457726
687	47 19 69	324 242 703	26·2106848	8·8237307	·001455604
688	47 33 44	325 660 672	26·2297541	8·8280099	·001453488
689	47 47 21	327 082 769	26·2488095	8·8322850	·001451379
690	47 61 00	328 509 000	26·2678511	8·8365559	·001449275
691	47 74 81	329 939 371	26·2868789	8·8408227	·001447178
692	47 88 64	331 373 888	26·3058929	8·8450854	·001445087
693	48 02 49	332 812 557	26·3248932	8·8493440	·001443001
694	48 16 36	334 255 384	26·3438797	8·8535985	·001440922
695	48 30 25	335 702 375	26·3628527	8·8578489	·001438849
696	48 44 16	337 153 536	26·3818119	8·8620952	·001436782
697	48 58 09	338 608 873	26·4007576	8·8663375	·001434720
698	48 72 04	340 068 392	26·4196896	8·8705757	·001432665
699	48 86 01	341 532 099	26·4386081	8·8748099	·001430615
700	49 00 00	343 000 000	26·4575131	8·8790400	·001428571
701	49 14 01	344 472 101	26·4764046	8·8832661	·001426534
702	49 28 04	345 948 408	26·4952826	8·8874882	·001424501
703	49 42 09	347 428 927	26·5141472	8·8917063	·001422475
704	49 56 16	348 913 664	26·5329983	8·8959204	·001420455
705	49 70 25	350 402 625	26·5518361	8·9001304	·001418440
706	49 84 36	351 895 816	26·5706605	8·9043366	·001416431
707	49 98 49	353 393 243	26·5894716	8·9085387	·001414427
708	50 12 64	354 894 912	26·6082694	8·9127369	·001412429
709	50 26 81	356 400 829	26·6270539	8·9169311	·001410437
710	50 41 00	357 911 000	26·6458252	8·9211214	·001408451
711	50 55 21	359 425 431	26·6645833	8·9253078	·001406470
712	50 69 44	360 944 128	26·6833281	8·9294902	·001404494
713	50 83 69	362 467 097	26·7020598	8·9336687	·001402525
714	50 97 96	363 994 344	26·7207784	8·9378433	·001400560
715	51 12 25	365 525 875	26·7394839	8·9420140	·001398601
716	51 26 56	367 061 696	26·7581763	8·9461809	·001396648
717	51 40 89	368 601 813	26·7768557	8·9503438	·001394700
718	51 55 24	370 146 232	26·7955220	8·9545029	·001392758
719	51 69 61	371 694 959	26·8141754	8·9586581	·001390821
720	51 84 00	373 248 000	26·8328157	8·9628095	·001388889
721	51 98 41	374 805 361	26·8514432	8·9669570	·001386963
722	52 12 84	376 367 048	26·8700577	8·9711007	·001385042
723	52 27 29	377 933 067	26·8886593	8·9752406	·001383126
724	52 41 76	379 503 424	26·9072481	8·9793766	·001381215
725	52 56 25	381 078 125	26·9258240	8·9835089	·001379310
726	52 70 76	382 657 176	26·9443872	8·9876373	·001377410
727	52 85 29	384 240 583	26·9629375	8·9917620	·001375516
728	52 99 84	385 828 352	26·9814751	8·9958829	·001373626
729	53 14 41	387 420 489	27·0000000	9·0000000	·001371742
730	53 29 00	389 017 000	27·0185122	9·0041134	·001369863
731	53 43 61	390 617 891	27·0370117	9·0082229	·001367989

No.	Square	Cube	Square Root	Cube Root	Reciprocal
732	53 58 24	392 223 168	27·0554985	9·0123288	·001366120
733	53 72 89	393 832 837	27·0739727	9·0164309	·001364256
734	53 87 56	395 446 904	27·0924344	9·0205293	·001362398
735	54 02 25	397 065 375	27·1108834	9·0246239	·001360544
736	54 16 96	398 688 256	27·1293199	9·0287149	·001358696
737	54 31 69	400 315 553	27·1477439	9·0328021	·001356852
738	54 46 44	401 947 272	27·1661554	9·0368857	·001355014
739	54 61 21	403 583 419	27·1845544	9·0409655	·001353180
740	54 76 00	405 224 000	27·2029410	9·0450417	·001351351
741	54 90 81	406 869 021	27·2213152	9·0491142	·001349528
742	55 05 64	408 518 488	27·2396769	9·0531831	·001347709
743	55 20 49	410 172 407	27·2580263	9·0572482	·001345895
744	55 35 36	411 830 784	27·2763634	9·0613098	·001344086
745	55 50 25	413 493 625	27·2946881	9·0653677	·001342282
746	55 65 16	415 160 936	27·3130006	9·0694220	·001340483
747	55 80 09	416 832 723	27·3313007	9·0734726	·001338688
748	55 95 04	418 508 992	27·3495887	9·0775197	·001336898
749	56 10 01	420 189 749	27 3678644	9·0815631	·001335113
750	56 25 00	421 875 000	27·3861279	9·0856030	·001333333
751	56 40 01	423 564 751	27·4043792	9·0896392	·001331558
752	56 55 04	425 259 008	27·4226184	9·0936719	·001329787
753	56 70 09	426 957 777	27·4408455	9·0977010	·001328021
754	56 85 16	428 661 064	27·4590604	9·1017265	·001326260
755	57 00 25	430 368 875	27·4772633	9·1057485	·001324503
756	57 15 36	432 081 216	27·4954542	9·1097669	·001322751
757	57 30 49	433 798 093	27·5136330	9·1137818	·001321004
758	57 45 64	435 519 512	27·5317998	9·1177931	·001319261
759	57 60 81	437 245 479	27·5499546	9·1218010	·001317523
760	57 76 00	438 976 000	27·5680975	9·1258053	·001315789
761	57 91 21	440 711 081	27·5862284	9·1298061	·001314060
762	58 06 44	442 450 728	27·6043475	9·1338034	·001312336
763	58 21 69	444 194 947	27·6224546	9·1377971	·001310616
764	58 36 96	445 943 744	27·6405499	9·1417874	·001308901
765	58 52 25	447 697 125	27·6586334	9·1457742	·001307190
766	58 67 56	449 455 096	27·6767050	9·1497576	·001305483
767	58 82 89	451 217 663	27·6947648	9·1537375	·001303781
768	58 98 24	452 984 832	27·7128129	9·1577139	·00 302083
769	59 13 61	454 756 609	27·7308492	9·1616869	·001300390
770	59 29 00	456 533 000	27·7488739	9·1656565	·001298701
771	59 44 41	458 314 011	27·7668868	9·1696225	·001297017
772	59 59 84	460 099 648	27·7848880	9·1735852	·001295337
773	59 75 29	461 889 917	27·8028775	9·1775445	·001293661
774	59 90 76	463 684 824	27·8208555	9·1815003	·001291990
775	60 06 25	465 484 375	27·8388218	9·1854527	·001290323
776	60 21 76	467 288 576	27·8567766	9·1894018	·001288660
777	60 37 29	469 097 433	27·8747197	9·1933474	·001287001
778	60 52 84	470 910 952	27·8926514	9·1972897	·001285347
779	60 68 41	472 729 139	27·9105715	9·2012286	·001283697
780	60 84 00	474 552 000	27·9284801	9·2051641	·001282051

No.	Square	Cube	Square Root	Cube Root	Reciprocal
781	60 99 61	476 379 541	27·9463772	9·2090962	·001280410
782	61 15 24	478 211 768	27·9642629	9·2130250	·001278772
783	61 30 89	480 048 687	27·9821372	9·2169505	·001277139
784	61 46 56	481 890 304	28·0000000	9·2208726	·001275510
785	61 62 25	483 736 625	28·0178515	9·2247914	·001273885
786	61 77 96	485 587 656	28·0356915	9·2287068	·001272265
787	61 93 69	487 443 403	28·0535203	9·2326189	·001270648
788	62 09 44	489 303 872	28·0713377	9·2365277	·001269036
789	62 25 21	491 169 069	28·0891438	9·2404333	·001267427
790	62 41 00	493 039 000	28·1069386	9·2443355	·001265823
791	62 56 81	494 913 671	28·1247222	9·2482344	·001264223
792	62 72 64	496 793 088	28·1424946	9·2521300	·001262626
793	62 88 49	498 677 257	28·1602557	9·2560224	·001261034
794	63 04 36	500 566 184	28·1780056	9·2599114	·001259446
795	63 20 25	502 459 875	28·1957444	9·2637973	·001257862
796	63 36 16	504 358 336	28·2134720	9·2676798	·001256281
797	63 52 09	506 261 573	28·2311884	9·2715592	·001254705
798	63 68 04	508 169 592	28·2488938	9·2754352	·001253133
799	63 84 01	510 082 399	28·2665881	9·2793081	·001251564
800	64 00 00	512 000 000	28·2842712	9·2831777	·001250000
801	64 16 01	513 922 401	28·3019434	9·2870440	·001248439
802	64 32 04	515 849 608	28·3196045	9·2909072	·001246883
803	64 48 09	517 781 627	28·3372546	9·2947671	·001245330
804	64 64 16	519 718 464	28·3548938	9·2986239	·001243781
805	64 80 25	521 660 125	28·3725219	9·3024775	·001242236
806	64 96 36	523 606 616	28·3901391	9·3063278	·001240695
807	65 12 49	525 557 943	28·4077454	9·3101750	·001239157
808	65 28 64	527 514 112	28·4253408	9·3140190	·001237624
809	65 44 81	529 475 129	28·4429253	9·3178599	·001236094
810	65 61 00	531 441 000	28·4604989	9·3216975	·001234568
811	65 77 21	533 411 731	28·4780617	9·3255320	·001233046
812	65 93 44	535 387 328	28·4956137	9·3293634	·001231527
813	66 09 69	537 367 797	28·5131549	9·3331916	·001230012
814	66 25 96	539 353 144	28·5306852	9·3370167	·001228501
815	66 42 25	541 343 375	28·5482048	9·3408386	·001226994
816	66 58 56	543 338 496	28·5657137	9·3446575	·001225490
817	66 74 89	545 338 513	28·5832119	9·3484731	·001223990
818	66 91 24	547 343 432	28·6006993	9·3522857	·001222494
819	67 07 61	549 353 259	28·6181760	9·3560952	·001221001
820	67 24 00	551 368 000	28·6356421	9·3599016	·001219512
821	67 40 41	553 387 661	28·6530976	9·3637049	·001218027
822	67 56 84	555 412 248	28·6705424	9·3675051	·001216545
823	67 73 29	557 441 767	28·6879766	9·3713022	·001215067
824	67 89 76	559 476 224	28·7054002	9·3750963	·001213592
825	68 06 25	561 515 625	28·7228132	9·3788873	·001212121
826	68 22 76	563 559 976	28·7402157	9·3826752	·001210654
827	68 39 29	565 609 283	28·7576077	9·3864600	·001209190
828	68 55 84	567 663 552	28·7749891	9·3902419	·001207729
829	68 72 41	569 722 789	28·7923601	9·3940206	·001206273

No.	Square	Cube	Square Root	Cube Root	Reciprocal
830	68 89 00	571 787 000	28·8097206	9·3977964	·001204819
831	69 05 61	573 856 191	28·8270706	9·4015691	·001203369
832	69 22 24	575 930 368	28·8444102	9·4053387	·001201923
833	69 38 89	578 009 537	28·8617394	9·4091054	·001200480
834	69 55 56	580 093 704	28·8790582	9·4128690	·001199041
835	69 72 25	582 182 875	28·8963666	9·4166297	·001197605
836	69 88 96	584 277 056	28·9136646	9·4203873	·001196172
837	70 05 69	586 376 253	28·9309523	9·4241420	·001194743
838	70 22 44	588 480 472	28·9482297	9·4278936	·001193317
839	70 39 21	590 589 719	28·9654967	9·4316423	·001191895
840	70 56 00	592 704 000	28·9827535	9·4353880	·001190476
841	70 72 81	594 823 321	29·0000000	9·4391307	·001189061
842	70 89 64	596 947 688	29·0172363	9·4428704	·001187648
843	71 06 49	599 077 107	29·0344623	9·4466072	·001186240
844	71 23 36	601 211 584	29·0516781	9·4503410	·001184834
845	71 40 25	603 351 125	29·0688837	9·4540719	·001183432
846	71 57 16	605 495 736	29·0860791	9·4577999	·001182033
847	71 74 09	607 645 423	29·1032644	9·4615249	·001180638
848	71 91 04	609 800 192	29·1204396	9·4652470	·001179245
849	72 08 01	611 960 049	29·1376046	9·4689661	·001177856
850	72 25 00	614 125 000	29·1547595	9·4726824	·001176471
851	72 42 01	616 295 051	29·1719043	9·4763957	·001175088
852	72 59 04	618 470 208	29·1890390	9·4801061	·001173709
853	72 76 09	620 650 477	29·2061637	9·4838136	·001172333
854	72 93 16	622 835 864	29·2232784	9·4875182	·001170960
855	73 10 25	625 026 375	29·2403830	9·4912200	·001169591
856	73 27 36	627 222 016	29·2574777	9·4949188	·001168224
857	73 44 49	629 422 793	29·2745623	9·4986147	·001166861
858	73 61 64	631 628 712	29·2916370	9·5023078	·001165501
859	73 78 81	633 839 779	29·3087018	9·5059980	·001164144
860	73 96 00	636 056 000	29·3257566	9·5096854	·001162791
861	74 13 21	638 277 381	29·3428015	9·5133699	·001161440
862	74 30 44	640 503 928	29·3598365	9·5170515	·001160093
863	74 47 69	642 735 647	29·3768616	9·5207303	·001158749
864	74 64 96	644 972 544	29·3938769	9·5244063	·001157407
865	74 82 25	647 214 625	29·4108823	9·5280794	·001156069
866	74 99 56	649 461 896	29·4278779	9·5317497	·001154734
867	75 16 89	651 714 363	29·4448637	9·5354172	·001153403
868	75 34 24	653 972 032	29·4618397	9·5390818	·001152074
869	75 51 61	656 234 909	29·4788059	9·5427437	·001150748
870	75 69 00	658 503 000	29·4957624	9·5464027	·001149425
871	75 86 41	660 776 311	29·5127091	9·5500589	·001148106
872	76 03 84	663 054 848	29·5296461	9·5537123	·001146789
873	76 21 29	665 338 617	29·5465734	9·5573630	·001145475
874	76 38 76	667 627 624	29·5634910	9·5610108	·001144165
875	76 56 25	669 921 875	29·5803989	9·5646559	·001142857
876	76 73 76	672 221 376	29·5972972	9·5682982	·001141553
877	76 91 29	674 526 133	29·6141858	9·5719377	·001140251
878	77 08 84	676 836 152	29·6310648	9·5755745	·001138952

No.	Square	Cube	Square Root	Cube Root	Reciprocal
879	77 26 41	679 151 439	29·6479342	9·5792085	·001137656
880	77 44 00	681 472 000	29·6647939	9·5828397	·001136364
881	77 61 61	683 797 841	29·6816442	9·5864682	·001135074
882	77 79 24	686 128 968	29·6984848	9·5900939	·001133787
883	77 96 89	688 465 387	29·7153159	9·5937169	·001132503
884	78 14 56	690 807 104	29·7321375	9·5973373	·001131222
885	78 32 25	693 154 125	29·7489496	9·6009548	·001129944
886	78 49 96	695 506 456	29·7657521	9·6045696	·001128668
887	78 67 69	697 864 103	29·7825452	9·6081817	·001127396
888	78 85 44	700 227 072	29·7993289	9·6117911	·001126126
889	79 03 21	702 595 369	29·8161030	9·6153977	·001124859
890	79 21 00	704 969 000	29·8328678	9·6190017	·001123596
891	79 38 81	707 347 971	29·8496231	9·6226030	·001122334
892	79 56 64	709 732 288	29·8663690	9·6262016	·001121076
893	79 74 49	712 121 957	29·8831056	9·6297975	·001119821
894	79 92 36	714 516 984	29·8998328	9·6333907	·001118568
895	80 10 25	716 917 375	29·9165506	9·6369812	·001117318
896	80 28 16	719 323 136	29·9332591	9·6405690	·001116071
897	80 46 09	721 734 273	29·9499583	9·6441542	·001114827
898	80 64 04	724 150 792	29·9666481	9·6477367	·001113586
899	80 82 01	726 572 699	29·9833287	9·6513166	·001112347
900	81 00 00	729 000 000	30·0000000	9·6548938	·001111111
901	81 18 01	731 432 701	30·0166620	9·6584684	·001109878
902	81 36 04	733 870 808	30·0333148	9·6620403	·001108647
903	81 54 09	736 314 327	30·0499584	9·6656096	·001107420
904	81 72 16	738 763 264	30·0665928	9·6691762	·001106195
905	81 90 25	741 217 625	30·0832179	9·6727403	·001104972
906	82 08 36	743 677 416	30·0998339	9·6763017	·001103753
907	82 26 49	746 142 643	30·1164407	9·6798604	·001102536
908	82 44 64	748 613 312	30·1330383	9·6834166	·001101322
909	82 62 81	751 089 429	30·1496269	9·6869701	·001100110
910	82 81 00	753 571 000	30·1662063	9·6905211	·001098901
911	82 99 21	756 058 031	30·1827765	9·6940694	·001097695
912	83 17 44	758 550 528	30·1993377	9·6976151	·001096491
913	83 35 69	761 048 497	30·2158899	9·7011583	·001095290
914	83 53 96	763 551 944	30·2324329	9·7046989	·001094092
915	83 72 25	766 060 875	30·2489669	9·7082369	·001092896
916	83 90 56	768 575 296	30·2654919	9·7117723	·001091703
917	84 08 89	771 095 213	30·2820079	9·7153051	·001090513
918	84 27 24	773 620 632	30·2985148	9·7188354	·001089325
919	84 45 61	776 151 559	30·3150128	9·7223631	·001088139
920	84 64 00	778 688 000	30·3315018	9·7258883	·001086957
921	84 82 41	781 229 961	30·3479818	9·7294109	·001085776
922	85 00 84	783 777 448	30·3644529	9·7329309	·001084599
923	85 19 29	786 330 467	30·3809151	9·7364484	·001083424
924	85 37 76	788 889 024	30·3973683	9·7399634	·001082251
925	85 56 25	791 453 125	30·4138127	9·7434758	·001081081
926	85 74 76	794 022 776	30·4302481	9·7469857	·001079914
927	85 93 29	796 597 983	30·4466747	9·7504930	·001078749

No.	Square	Cube	Square Root	Cube Root	Reciprocal
928	86 11 84	799 178 752	30·4630924	9·7539979	·001077586
929	86 30 41	801 765 089	30·4795013	9·7575002	·001076426
930	86 49 00	804 357 000	30·4959014	9·7610001	·001075269
931	86 67 61	806 954 491	30·5122926	9·7644974	·001074114
932	86 86 24	809 557 568	30·5286750	9·7679922	·001072961
933	87 04 89	812 166 237	30·5450487	9·7714845	·001071811
934	87 23 56	814 780 504	30·5614136	9·7749743	·001070664
935	87 42 25	817 400 375	30·5777697	9·7784616	·001069519
936	87 60 96	820 025 856	30·5941171	9·7819466	·001068376
937	87 79 69	822 656 953	30·6104557	9·7854288	·001067236
938	87 98 44	825 293 672	30·6267857	9·7889087	·001066098
939	88 17 21	827 936 019	30·6431069	9·7923861	·001064963
940	88 36 00	830 584 000	30·6594194	9·7958611	·001063830
941	88 54 81	833 237 621	30·6757233	9·7993336	·001062699
942	88 73 64	835 896 888	30·6920185	9·8028036	·001061571
943	88 92 49	838 561 807	30·7083051	9·8062711	·001060445
944	89 11 36	841 232 384	30·7245830	9·8097362	·001059322
945	89 30 25	843 908 625	30·7408523	9·8131989	·001058201
946	89 49 16	846 590 536	30·7571130	9·8166591	·001057082
947	89 68 09	849 278 123	30·7733651	9·8201169	·001055966
948	89 87 04	851 971 392	30·7896086	9·8235723	·001054852
949	90 06 01	854 670 349	30·8058436	9·8270252	·001053741
950	90 25 00	857 375 000	30·8220700	9·8304757	·001052632
951	90 44 01	860 085 351	30·8382879	9·8339238	·001051525
952	90 63 04	862 801 408	30·8544972	9·8373695	·001050420
953	90 82 09	865 523 177	30·8706981	9·8408127	·001049318
954	91 01 16	868 250 664	30·8868904	9·8442536	·001048218
955	91 20 25	870 983 875	30·9030743	9·8476920	·001047120
956	91 39 36	873 722 816	30·9192497	9·8511280	·001046025
957	91 58 49	876 467 493	30·9354166	9·8545617	·001044932
958	91 77 64	879 217 912	30·9515751	9·8579929	·001043841
959	91 96 81	881 974 079	30·9677251	9·8614218	·001042753
960	92 16 00	884 736 000	30·9838668	9·8648483	·001041667
961	92 35 21	887 503 681	31·0000000	9·8682724	·001040583
962	92 54 44	890 277 128	31·0161248	9·8716941	·001039501
963	92 73 69	893 056 347	31·0522418	9·8751135	·001038422
964	92 92 96	895 841 344	31·0483494	9·8785305	·001037344
965	93 12 25	898 632 125	31·0644491	9·8819451	·001036269
966	93 31 56	901 428 696	31·0805405	9·8853574	·001035197
967	93 50 89	904 231 063	31·0966236	9·8887673	·001034126
968	93 70 24	907 039 232	31·1126984	9·8921749	·001033058
969	93 89 61	909 853 209	31·1287648	9·8955801	·001031992
970	94 09 00	912 673 000	31·1448230	9·8989830	·001030928
971	94 28 41	915 498 611	31·1608729	9·9023835	·001029866
972	94 47 84	918 330 048	31·1769145	9·9057817	·001028807
973	94 67 29	921 167 317	31·1929479	9·9091776	·001027749
974	94 86 76	924 010 424	31·2089731	9·9125712	·001026694
975	95 06 25	926 859 375	31·2249900	9·9159624	·001025641
976	95 25 76	929 714 176	31·2409987	9·9193513	·001024590

No.	Square	Cube	Square Root	Cube Root	Reciprocal
977	95 45 29	932 574 833	31·2569992	9·9227379	·001023541
978	95 64 84	935 441 352	31·2729915	9·9261222	·001022495
979	95 84 41	938 313 739	31·2889757	9·9295042	·001021450
980	96 04 00	941 192 000	31·3049517	9·9328839	·001020408
981	96 23 61	944 076 141	31·3209195	9·9362613	·001019368
982	96 43 24	946 966 168	31·3368792	9·9396363	·001018330
983	96 62 89	949 862 087	31·3528308	9·9430092	·001017294
984	96 82 56	952 763 904	31·3687743	9·9463797	·001016260
985	97 02 25	955 671 625	31·3847097	9·9497479	·001015228
986	97 21 96	958 585 256	31·4006369	9·9531138	·001014199
987	97 41 69	961 504 803	31·4165561	9·9564775	·001013171
988	97 61 44	964 430 272	31·4324673	9·9598389	·001012146
989	97 81 21	967 361 669	31·4483704	9·9631981	·001011122
990	98 01 00	970 299 000	31·4642654	9·9665549	·001010101
991	98 20 81	973 242 271	31·4801525	9·9699095	·001009082
992	98 40 64	976 191 488	31·4960315	9·9732619	·001008065
993	98 60 49	979 146 657	31·5119025	9·9766120	·001007049
994	98 80 36	982 107 784	31·5277655	9·9799599	·001006036
995	99 00 25	985 074 875	31·5436206	9 9833055	·001005025
996	99 20 16	988 047 936	31·5594677	9·9866488	·001004016
997	99 40 09	991 026 973	31·5753068	9·9899900	·001003009
998	99 60 04	994 011 992	31·5911380	9·9933289	·001002004
999	99 80 01	997 002 999	31·6069613	9·9966656	·001001001
1000	1 00 00 00	1 000 000 000	31·6227766	10·0000000	·001000000
1001	1 00 20 01	1 003 003 001	31·6385840	10·0033322	·000999001
1002	1 00 40 04	1 006 012 008	31·6543836	10·0066622	·000998004
1003	1 00 60 09	1 009 027 027	31·6701752	10·0099899	·000997009
1004	1 00 80 16	1 012 048 064	31·6859590	10·0133155	·000996015
1005	1 01.00 25	1 015 075 125	31·7017349	10·0166389	·000995024
1006	1 01 20 36	1 018 108 216	31·7175030	10·0199601	·000994035
1007	1 01 40 49	1 021 147 343	31·7332633	10·0232791	·000993048
1008	1 01 60 64	1 024 192 512	31·7490157	10·0265958	·000992063
1009	1 01 80 81	1 027 243 729	31·7647603	10·0299104	·000991080
1010	1 02 01 00	1 030 301 000	31·7804972	10·0332228	·000990099
1011	1 02 21 21	1 033 364 331	31·7962262	10·0365330	·000989119
1012	1 02 41 44	1 036 433 728	31·8119474	10·0398410	·000988142
1013	1 02 61 69	1 039 509 197	31·8276609	10·0431469	·000987166
1014	1 02 81 96	1 042 590 744	31·8433666	10·0464506	·000986193
1015	1 03 02 25	1 045 678 375	31·8590646	10·0497521	·000985221
1016	1 03 22 56	1 048 772 096	31·8747549	10·0530514	·000984252
1017	1 03 42 89	1 051 871 913	31·8904374	10·0563485	·000983284
1018	1 03 63 24	1 054 977 832	31·9061123	10·0596435	·000982318
1019	1 03 83 61	1 058 089 859	31·9217794	10·0629364	·000981354
1020	1 04 04 00	1 061 208 000	31·9374388	10·0662271	·000980392
1021	1 04 24 41	1 064 332 261	31·9530906	10·0695156	·000979431
1022	1 04 44 84	1 067 462 648	31·9687347	10·0728020	·000978473
1023	1 04 65 29	1 070 599 167	31·9843712	10·0760863	·000977517
1024	1 04 85 76	1 073 741 824	32·0000000	10·0793684	·000976562
1025	1 05 06 25	1 076 890 625	32·0156212	10·0826484	·000975609

No.	Square	Cube	Square Root	Cube Root	Reciprocal
026	1 05 26 76	1 080 045 576	32·0312348	10·0859262	·0009746589
027	1 05 47 29	1 083 206 683	32·0468407	10·0892019	·0009737098
028	1 05 67 84	1 086 373 952	32·0624391	10·0924755	·0009727626
029	1 05 88 41	1 089 547 389	32·0780298	10·0957469	·0009718173
030	1 06 09 00	1 092 727 000	32·0936131	10·0990163	·0009708738
031	1 06 29 61	1 095 912 791	32·1091887	10·1022835	·0009699321
032	1 06 50 24	1 099 104 768	32·1247568	10·1055487	·0009689922
033	1 06 70 89	1 102 302 937	32·1403173	10·1088117	·0009680542
034	1 06 91 56	1 105 507 304	32·1558704	10·1120726	·0009671180
035	1 07 12 25	1 108 717 875	32·1714159	10·1153314	·0009661836
036	1 07 32 96	1 111 934 656	32·1869539	10·1185882	·0009652510
037	1 07 53 69	1 115 157 653	32·2024844	10·1218428	·0009643202
038	1 07 74 44	1 118 386 872	32·2180074	10·1250953	·0009633911
039	1 07 95 21	1 121 622 319	32·2335229	10·1283457	·0009624639
040	1 08 16 00	1 124 864 000	32·2490310	10·1315941	·0009615385
041	1 08 36 81	1 128 111 921	32·2645316	10·1348403	·0009606148
042	1 08 57 64	1 131 366 088	32·2800248	10·1380845	·0009596929
043	1 08 78 49	1 134 626 507	32·2955105	10·1413266	·0009587728
044	1 08 99 36	1 137 893 184	32·3109888	10·1445667	·0009578544
045	1 09 20 25	1 141 166 125	32·3264598	10·1478047	·0009569378
046	1 09 41 16	1 144 445 336	32·3419233	10·1510406	·0009560229
047	1 09 62 09	1 147 730 323	32·3573794	10·1542744	·0009551098
048	1 09 83 04	1 151 022 592	32·3728281	10·1575062	·0009541985
049	1 10 04 01	1 154 320 649	32·3882695	10·1607359	·0009532888
050	1 10 25 00	1 157 625 000	32·4037035	10·1639636	·0009523810
051	1 10 46 01	1 160 935 651	32·4191301	10·1671893	·0009514748
052	1 10 67 04	1 164 252 608	32·4345495	10·1704129	·0009505703
053	1 10 88 09	1 167 575 877	32·4499615	10·1736344	·0009496676
054	1 11 09 16	1 170 905 464	32·4653662	10·1768539	·0009487666
055	1 11 30 25	1 174 241 375	32·4807635	10·1800714	·0009478673
056	1 11 51 36	1 177 583 616	32·4961536	10·1832868	·0009469697
057	1 11 72 49	1 180 932 193	32·5115364	10·1865002	·0009460738
058	1 11 93 64	1 184 287 112	32·5269119	10·1897116	·0009451796
059	1 12 14 81	1 187 648 379	32·5422802	10·1929209	·0009442871
060	1 12 36 00	1 191 016 000	32·5576412	10·1961283	·0009433962
061	1 12 57 21	1 194 389 981	32 5729949	10·1993336	·0009425071
062	1 12 78 44	1 197 770 328	32·5883415	10·2025369	·0009416196
063	1 12 99 69	1 201 157 047	32·6036807	10·2057382	·0009407338
064	1 13 20 96	1 204 550 144	32·6190129	10·2089375	·0009398496
065	1 13 42 25	1 207 949 625	32·6343377	10·2121347	·0009389671
066	1 13 63 56	1 211 355 496	32·6496554	10·2153300	·0009380863
067	1 13 84 89	1 214 767 763	32·6649659	10·2185233	·0009372071
068	1 14 06 24	1 218 186 432	32·6802693	10·2217146	·0009363296
069	1 14 27 61	1 221 611 509	32·6955654	10·2249039	·0009354537
070	1 14 49 00	1 225 043 000	32·7108544	10·2280912	·0009345794
071	1 14 70 41	1 228 480 911	32·7261363	10·2312766	·0009337068
072	1 14 91 84	1 231 925 248	32·7414111	10·2344599	·0009328358
073	1 15 13 29	1 235 376 017	32·7566787	10·2376413	·0009319664
074	1 15 34 76	1 238 833 224	32·7719392	10·2408207	·0009310987

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1075	1 15 56 25	1 242 296 875	32·7871926	10·2439981	·0009302326
1076	1 15 77 76	1 245 766 976	32·8024389	10·2471735	·0009293680
1077	1 15 99 29	1 249 243 533	32·8176782	10·2503470	·0009285051
1078	1 16 20 84	1 252 726 552	32·8329103	10·2535186	·0009276438
1079	1 16 42 41	1 256 216 039	32·8481354	10·2566881	·0009267841
1080	1 16 64 00	1 259 712 000	32·8633535	10·2598557	·0009259259
1081	1 16 85 61	1 263 214 441	32·8785644	10·2630213	·0009250694
1082	1 17 07 24	1 266 723 368	32·8937684	10·2661850	·0009242144
1083	1 17 28 89	1 270 238 787	32·9089653	10·2693467	·0009233610
1084	1 17 50 56	1 273 760 704	32·9241553	10·2725065	·0009225092
1085	1 17 72 25	1 277 289 125	32·9393382	10·2756644	·0009216590
1086	1 17 93 96	1 280 824 056	32·9545141	10·2788203	·0009208103
1087	1 18 15 69	1 284 365 503	32·9696830	10·2819743	·0009199632
1088	1 18 37 44	1 287 913 472	32·9848450	10·2851264	·0009191176
1089	1 18 59 21	1 291 467 969	33·0000000	10·2882765	·0009182736
1090	1 18 81 00	1 295 029 000	33·0151480	10·2914247	·0009174312
1091	1 19 02 81	1 298 596 571	33·0302891	10·2945709	·0009165903
1092	1 19 24 64	1 302 170 688	33·0454233	10·2977153	·0009157509
1093	1 19 46 49	1 305 751 357	33·0605505	10·3008577	·0009149131
1094	1 19 68 36	1 309 338 584	33·0756708	10·3039982	·0009140768
1095	1 19 90 25	1 312 932 375	33·0907842	10·3071368	·0009132420
1096	1 20 12 16	1 316 532 736	33·1058907	10·3102735	·0009124088
1097	1 20 34 09	1 320 139 673	33·1209903	10·3134083	·0009115770
1098	1 20 56 04	1 323 753 192	33·1360830	10·3165411	·0009107468
1099	1 20 78 01	1 327 373 299	33·1511689	10·3196721	·0009099181
1100	1 21 00 00	1 331 000 000	33·1662479	10·3228012	·0009090909
1101	1 21 22 01	1 334 633 301	33·1813200	10·3259284	·0009082652
1102	1 21 44 04	1 338 273 208	33·1963853	10·3290537	·0009074410
1103	1 21 66 09	1 341 919 727	33·2114438	10·3321770	·0009066183
1104	1 21 88 16	1 345 572 864	33·2264955	10·3352985	·0009057971
1105	1 22 10 25	1 349 232 625	33·2415403	10·3384181	·0009049774
1106	1 22 32 36	1 352 899 016	33·2565783	10·3415358	·0009041591
1107	1 22 54 49	1 356 572 043	33·2716095	10·3446517	·0009033424
1108	1 22 76 64	1 360 251 712	33·2866339	10·3477657	·0009025271
1109	1 22 98 81	1 363 938 029	33·3016516	10·3508778	·0009017133
1110	1 23 21 00	1 367 631 000	33·3166625	10·3539880	·0009009009
1111	1 23 43 21	1 371 330 631	33·3316666	10·3570964	·0009000900
1112	1 23 65 44	1 375 036 928	33·3466640	10·3602029	·0008992806
1113	1 23 87 69	1 378 749 897	33·3616546	10·3633076	·0008984726
1114	1 24 09 96	1 382 469 544	33·3766385	10·3664103	·0008976661
1115	1 24 32 25	1 386 195 875	33·3916157	10·3695113	·0008968610
1116	1 24 54 56	1 389 928 896	33·4065862	10·3726103	·0008960573
1117	1 24 76 89	1 393 668 613	33·4215499	10·3757076	·0008952551
1118	1 24 99 24	1 397 415 032	33·4365070	10·3788030	·0008944544
1119	1 25 21 61	1 401 168 159	33·4514573	10·3818965	·0008936550
1120	1 25 44 00	1 404 928 000	33·4664011	10·3849882	·0008928571
1121	1 25 66 41	1 408 694 561	33·4813381	10·3880781	·0008920607
1122	1 25 88 84	1 412 467 848	33·4962684	10·3911661	·0008912656
1123	1 26 11 29	1 416 247 867	33·5111921	10·3942523	·0008904720

	Square	Cube	Square Root	Cube Root	Reciprocal
[illegible]	1 26 33 76	1 420 034 624	33·5261092	10·3973366	·0008896797
[illegible]	1 26 56 25	1 423 828 125	33·5410196	10·4004192	·0008888889
[illegible]	1 26 78 76	1 427 628 376	33·5559234	10·4034999	·0008880995
7	1 27 01 29	1 431 435 388	33·5708206	10·4065787	·0008873114
3	1 27 23 84	1 435 249 152	33·5857112	10·4096557	·0008865248
9	1 27 46 41	1 439 069 689	33·6005952	10·4127310	·0008857396
0	1 27 69 00	1 442 897 000	33·6154726	10·4158044	·0008849558
1	1 27 91 61	1 446 731 091	33·6303434	10·4188760	·0008841733
2	1 28 14 24	1 450 571 968	33·6452077	10·4219458	·0008833922
3	1 28 36 89	1 454 419 637	33·6600653	10·4250138	·0008826125
4	1 28 59 56	1 458 274 104	33·6749165	10·4280800	·0008818342
35	1 28 82 25	1 462 135 375	33·6897610	10·4311443	·0008810573
36	1 29 04 96	1 466 003 456	33·7045991	10·4342069	·0008802817
37	1 29 27 69	1 469 878 353	33·7194306	10·4372677	·0008795075
38	1 29 50 44	1 473 760 072	33·7342556	10·4403267	·0008787346
39	1 29 73 21	1 477 648 619	33·7490741	10·4433839	·0008779631
40	1 29 96 00	1 481 544 000	33·7638860	10·4464393	·0008771930
41	1 30 18 81	1 485 446 221	33·7786915	10·4494929	·0008764242
42	1 30 41 64	1 489 355 288	33·7934905	10·4525448	·0008756567
43	1 30 64 49	1 493 271 207	33·8082830	10·4555948	·0008748906
144	1 30 87 36	1 497 193 984	33·8230691	10·4586431	·0008741259
145	1 31 10 25	1 501 123 625	33·8378486	10·4616896	·0008733624
146	1 31 33 16	1 505 060 136	33·8526218	10·4647343	·0008726003
147	1 31 56 09	1 509 003 523	33·8673884	10·4677773	·0008718396
148	1 31 79 04	1 512 953 792	33·8821487	10·4708185	·0008710801
149	1 32 02 01	1 516 910 949	33·8969025	10·4738579	·0008703220
150	1 32 25 00	1 520 875 000	33·9116499	10·4768955	·0008695652
151	1 32 48 01	1 524 845 951	33·9263909	10·4799314	·0008688097
152	1 32 71 04	1 528 823 808	33·9411255	10·4829656	·0008680556
153	1 32 94 09	1 532 808 577	33·9558537	10·4859980	·0008673027
1154	1 33 17 16	1 536 800 264	33·9705755	10·4890286	·0008665511
155	1 33 40 25	1 540 798 875	33·9852910	10·4920575	·0008658009
156	1 33 63 36	1 544 804 416	34·0000000	10·4950847	·0008650519
157	1 33 86 49	1 548 816 893	34·0147027	10·4981101	·0008643042
158	1 34 09 64	1 552 836 312	34·0293990	10·5011337	·0008635579
159	1 34 32 81	1 556 862 679	34·0440890	10·5041556	·0008628128
160	1 34 56 00	1 560 896 000	34·0587727	10·5071757	·0008620690
161	1 34 79 21	1 564 936 281	34·0734501	10·5101942	·0008613264
162	1 35 02 44	1 568 983 528	34·0881211	10·5132109	·0008605852
163	1 35 25 69	1 573 037 747	34·1027858	10·5162259	·00085984[illegible]2
164	1 35 48 96	1 577 098 944	34·1174442	10·5192391	·000859.065
165	1 35 72 25	1 581 167 125	34·1320963	10·5222506	·0008583691
166	1 35 95 56	1 585 242 296	34·1467422	10·5252604	·0008576329
167	1 36 18 89	1 589 324 463	34·1613817	10·5282685	·0008568980
168	1 36 42 24	1 593 413 632	34·1760150	10·5312749	·0008561644
169	1 36 65 61	1 597 509 809	34·1906420	10·5342795	·0008554320
170	1 36 89 00	1 601 613 000	34·2052627	10·5372825	·0008547009
171	1 37 12 41	1 605 723 211	34·2198773	10·5402837	·0008539710
172	1 37 35 84	1 609 840 448	34·2344855	10·5432832	·0008532423

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1173	1 37 59 29	1 613 964 717	34·2490875	10·5462810	·0008525149
1174	1 37 82 76	1 618 096 024	34·2636834	10·5492771	·0008517888
1175	1 38 06 25	1 622 234 375	34·2782730	10·5522715	·0008510638
1176	1 38 29 76	1 626 379 776	34·2928564	10·5552642	·0008503401
1177	1 38 53 29	1 630 532 233	34·3074336	10·5582552	·0008496177
1178	1 38 76 84	1 634 691 752	34·3220046	10·5612445	·0008488964
1179	1 39 00 41	1 638 858 339	34·3365694	10·5642322	·0008481764
1180	1 39 24 00	1 643 032 000	34·3511281	10·5672181	·0008474576
1181	1 39 47 61	1 647 212 741	34·3656805	10·5702024	·0008467401
1182	1 39 71 24	1 651 400 568	34·3802268	10·5731849	·0008460237
1183	1 39 94 89	1 655 595 487	34·3947670	10·5761658	·0008453085
1184	1 40 18 56	1 659 797 504	34·4093011	10·5791449	·0008445946
1185	1 40 42 25	1 664 006 625	34·4238289	10·5821225	·0008438819
1186	1 40 65 96	1 668 222 856	34·4383507	10·5850983	·0008431703
1187	1 40 89 69	1 672 446 203	34·4528663	10·5880725	·0008424600
1188	1 41 13 44	1 676 676 672	34·4673759	10·5910450	·0008417508
1189	1 41 37 21	1 680 914 269	34·4818793	10·5940158	·0008410429
1190	1 41 61 00	1 685 159 000	34·4963766	10·5969850	·0008403361
1191	1 41 84 81	1 689 410 871	34·5108678	10·5999525	·0008396306
1192	1 42 08 64	1 693 669 888	34·5253530	10·6029184	·0008389262
1193	1 42 32 49	1 697 936 057	34·5398321	10·6058826	·0008382230
1194	1 42 56 36	1 702 209 384	34·5543051	10·6088451	·0008375209
1195	1 42 80 25	1 706 489 875	34·5687720	10·6118060	·0008368201
1196	1 43 04 16	1 710 777 536	34·5832329	10·6147652	·0008361204
1197	1 43 28 09	1 715 072 373	34·5976879	10·6177228	·0008354219
1198	1 43 52 04	1 719 374 392	34·6121366	10·6206788	·0008347245
1199	1 43 76 01	1 723 683 599	34·6265794	10·6236331	·0008340284
1200	1 44 00 00	1 728 000 000	34·6410162	10·6265857	·0008333333
1201	1 44 24 01	1 732 323 601	34·6554469	10·6295367	·0008326395
1202	1 44 48 04	1 736 654 408	34·6698716	10·6324860	·0008319468
1203	1 44 72 09	1 740 992 427	34·6842904	10·6354338	·0008312552
1204	1 44 96 16	1 745 337 664	34·6987031	10·6383799	·0008305648
1205	1 45 20 25	1 749 690 125	34·7131099	10·6413244	·0008298755
1206	1 45 44 36	1 754 049 816	34·7275107	10·6442672	·0008291874
1207	1 45 68 49	1 758 416 743	34·7419055	10·6472085	·0008285004
1208	1 45 92 64	1 762 790 912	34·7562944	10·6501480	·0008278146
1209	1 46 16 81	1 767 172 329	34·7706773	10·6530860	·0008271299
1210	1 46 41 00	1 771 561 000	34·7850543	10·6560223	·0008264463
1211	1 46 65 21	1 775 956 931	34·7994253	10·6589570	·0008257638
1212	1 46 89 44	1 780 360 128	34·8137904	10·6618902	·0008250825
1213	1 47 13 69	1 784 770 597	34·8281495	10·6648217	·0008244023
1214	1 47 37 96	1 789 188 344	34·8425028	10·6677516	·0008237232
1215	1 47 62 25	1 793 613 375	34·8568501	10·6706799	·0008230453
1216	1 47 86 56	1 798 045 696	34·8711915	10·6736066	·0008223684
1217	1 48 10 89	1 802 485 313	34·8855271	10·6765317	·0008216927
1218	1 48 35 24	1 806 932 232	34·8998567	10·6794552	·0008210181
1219	1 48 59 61	1 811 386 459	34·9141805	10·6823771	·0008203445
1220	1 48 84 00	1 815 848 000	34·9284984	10·6852973	·0008196721
1221	1 49 08 41	1 820 316 861	34·9428104	10·6882160	·0008190008

Square	Cube	Square Root	Cube Root	Reciprocal
1 49 32 84	1 824 793 048	34·9571166	10·6911331	·0008183306
1 49 57 29	1 829 276 567	34·9714169	10·6940436	·0008176615
1 49 81 76	1 833 767 424	34·9857114	10·6969625	·0008169935
1 50 06 25	1 838 265 625	35·0000000	10·6998748	·0008163265
1 50 30 76	1 842 771 176	35·0142828	10·7027855	·0008156607
1 50 55 29	1 847 284 083	35·0285598	10·7056947	·0008149959
1 50 79 84	1 851 804 352	35·0428309	10·7086023	·0008143322
1 51 04 41	1 856 331 989	35·0570963	10·7115083	·0008136696
1 51 29 00	1 860 867 000	35·0713558	10·7144127	·0008130081
1 51 53 61	1 865 409 391	35·0856096	10·7173155	·0008123477
1 51 78 24	1 869 959 168	35·0998575	10·7202168	·0008116883
1 52 02 89	1 874 516 337	35·1140997	10·7231165	·0008110300
1 52 27 56	1 879 080 904	35·1283361	10·7260146	·0008103728
1 52 52 25	1 883 652 875	35·1425668	10·7289112	·0008097166
1 52 76 96	1 888 232 256	35·1567917	10·7318062	·0008090615
1 53 01 69	1 892 819 053	35·1710108	10·7346997	·0008084074
1 53 26 44	1 897 413 272	35·1852242	10·7375916	·0008077544
1 53 51 21	1 902 014 919	35·1994318	10·7404819	·0008071025
1 53 76 00	1 906 624 000	35·2136337	10·7433707	·0008064516
1 54 00 81	1 911 240 521	35·2278299	10·7462579	·0008058018
1 54 25 64	1 915 864 488	35·2420204	10·7491436	·0008051530
1 54 50 49	1 920 495 907	35·2562051	10·7520277	·0008045052
1 54 75 36	1 925 134 784	35·2703842	10·7549103	·0008038585
1 55 00 25	1 929 781 125	35·2845575	10·7577913	·0008032129
1 55 25 16	1 934 434 936	35·2987252	10·7606708	·0008025682
1 55 50 09	1 939 096 223	35·3128872	10·7635488	·0008019246
55 75 04	1 943 764 992	35·3270435	10·7664252	·0008012821
56 00 01	1 948 441 249	35·3411941	10·7693001	·0008006405
56 25 00	1 953 125 000	35·3553391	10·7721735	·0008000000
56 50 01	1 957 816 251	35·3694784	10·7750453	·0007993605
56 75 04	1 962 515 008	35·3836120	10·7779156	·0007987220
57 00 09	1 967 221 277	35·3977400	10·7807843	·0007980846
57 25 16	1 971 935 064	35·4118624	10·7836516	·0007974482
57 50 25	1 976 656 375	35·4259792	10·7865173	·0007968127
57 75 36	1 981 385 216	35·4400903	10·7893815	·0007961783
58 00 49	1 986 121 593	35·4541958	10·7922441	·0007955449
58 25 64	1 990 865 512	35·4682957	10·7951053	·0007949126
58 50 81	1 995 616 979	35·4823900	10·7979649	·0007942812
58 76 00	2 000 376 000	35·4964787	10·8008230	·0007936508
59 01 21	2 005 142 581	35·5105618	10·8036797	·0007930214
59 26 44	2 009 916 728	35·5246393	10·8065348	·0007923930
59 51 69	2 014 698 447	35·5387113	10·8093884	·0007917656
59 76 96	2 019 487 744	35·5527777	10·8122404	·0007911392
60 02 25	2 024 284 625	35·5668385	10·8150909	·0007905138
60 27 56	2 029 089 096	35·5808937	10·8179400	·0007898894
60 52 89	2 033 901 163	35·5949434	10·8207876	·0007892660
60 78 24	2 038 720 832	35·6089876	10·8236336	·0007886435
61 03 61	2 043 548 109	35·6230262	10·8264782	·0007880221
61 29 00	2 048 383 000	35·6370593	10·8293213	·0007874016

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1271	1 61 54 41	2 053 225 511	35·6510869	10·8321629	·0007867821
1272	1 61 79 84	2 058 075 648	35·6651090	10·8350030	·0007861635
1273	1 62 05 29	2 062 933 417	35·6791255	10·8378416	·0007855460
1274	1 62 30 76	2 067 798 824	35·6931366	10·8406788	·0007849294
1275	1 62 56 25	2 072 671 875	35·7071421	10·8435144	·0007843137
1276	1 62 81 76	2 077 552 576	35·7211422	10·8463485	·0007836991
1277	1 63 07 29	2 082 440 933	35·7351367	10·8491812	·0007830854
1278	1 63 32 84	2 087 336 952	35·7491258	10·8520125	·0007824726
1279	1 63 58 41	2 092 240 639	35·7631095	10·8548422	·0007818608
1280	1 63 84 00	2 097 152 000	35·7770876	10·8576704	·0007812500
1281	1 64 09 61	2 102 071 041	35·7910603	10·8604972	·0007806401
1282	1 64 35 24	2 106 997 768	35·8050276	10·8633225	·0007800312
1283	1 64 60 89	2 111 932 187	35·8189894	10·8661464	·0007794232
1284	1 64 86 56	2 116 874 304	35·8329457	10·8689687	·0007788162
1285	1 65 12 25	2 121 824 125	35·8468966	10·8717897	·0007782101
1286	1 65 37 96	2 126 781 656	35·8608421	10·8746091	·0007776050
1287	1 65 63 69	2 131 746 903	35·8747822	10·8774271	·0007770008
1288	1 65 89 44	2 136 719 872	35·8887169	10·8802436	·0007763975
1289	1 66 15 21	2 141 700 569	35·9026461	10·8830587	·0007757952
1290	1 66 41 00	2 146 689 000	35·9165699	10·8858723	·0007751938
1291	1 66 66 81	2 151 685 171	35·9304884	10·8886845	·0007745933
1292	1 66 92 64	2 156 689 088	35·9444015	10·8914952	·0007739938
1293	1 67 18 49	2 161 700 757	35·9583092	10·8943044	·0007733952
1294	1 67 44 36	2 166 720 184	35·9722115	10·8971123	·0007727975
1295	1 67 70 25	2 171 747 375	35·9861084	10·8999186	·0007722008
1296	1 67 96 16	2 176 782 336	36·0000000	10·9027235	·0007716049
1297	1 68 22 09	2 181 825 073	36·0138862	10·9055269	·0007710100
1298	1 68 48 04	2 186 875 592	36·0277671	10·9083290	·0007704160
1299	1 68 74 01	2 191 933 899	36·0416426	10·9111296	·0007698229
1300	1 69 00 00	2 197 000 000	36·0555128	10·9139287	·0007692308
1301	1 69 26 01	2 202 073 901	36·0693776	10·9167265	·0007686395
1302	1 69 52 04	2 207 155 608	36·0832371	10·9195228	·0007680492
1303	1 69 78 09	2 212 245 127	36·0970913	10·9223177	·0007674597
1304	1 70 04 16	2 217 342 464	36·1109402	10·9251111	·0007668712
1305	1 70 30 25	2 222 447 625	36·1247837	10·9279031	·0007662835
1306	1 70 56 36	2 227 560 616	36·1386220	10·9306937	·0007656968
1307	1 70 82 49	2 232 681 443	36·1524550	10·9334829	·0007651109
1308	1 71 08 64	2 237 810 112	36·1662826	10·9362706	·0007645260
1309	1 71 34 81	2 242 946 629	36·1801050	10·9390569	·0007639419
1310	1 71 61 00	2 248 091 000	36·1939221	10·9418418	·0007633588
1311	1 71 87 21	2 253 243 231	36·2077340	10·9446253	·0007627765
1312	1 72 13 44	2 258 403 328	36·2215406	10·9474074	·0007621951
1313	1 72 39 69	2 263 571 297	36·2353419	10·9501880	·0007616146
1314	1 72 65 96	2 268 747 144	36·2491379	10·9529673	·0007610350
1315	1 72 92 25	2 273 930 875	36·2629287	10·9557451	·0007604563
1316	1 73 18 56	2 279 122 496	36·2767143	10·9585215	·0007598784
1317	1 73 44 89	2 284 322 013	36·2904946	10·9612965	·0007593014
1318	1 73 71 24	2 289 529 432	36·3042697	10·9640701	·0007587253
1319	1 73 97 61	2 294 744 759	36·3180396	10·9668423	·0007581501

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1320	1 74 24 00	2 299 968 000	36·3318042	10·9696131	·0007575758
1321	1 74 50 41	2 305 199 161	36·3455637	10·9723825	·0007570023
1322	1 74 76 84	2 310 438 248	36·3593179	10·9751505	·0007564297
1323	1 75 03 29	2 315 685 267	36·3730670	10·9779171	·0007558579
1324	1 75 29 76	2 320 940 224	36·3868108	10·9806823	·0007552870
1325	1 75 56 25	2 326 203 125	36·4005494	10·9834462	·0007547170
1326	1 75 82 76	2 331 473 976	36·4142829	10·9862086	·0007541478
1327	1 76 09 29	2 336 752 783	36·4280112	10·9889696	·0007535795
1328	1 76 35 84	2 342 039 552	36·4417343	10·9917293	·0007530120
1329	1 76 62 41	2 347 334 289	36·4554523	10·9944876	·0007524454
1330	1 76 89 00	2 352 637 000	36·4691650	10·9972445	·0007518797
1331	1 77 15 61	2 357 947 691	36·4828727	11·0000000	·0007513148
1332	1 77 42 24	2 363 266 368	36·4965752	11·0027541	·0007507508
1333	1 77 68 89	2 368 593 037	36·5102725	11·0055069	·0007501875
1334	1 77 95 56	2 373 927 704	36·5239647	11·0082583	·0007496252
1335	1 78 22 25	2 379 270 375	36·5376518	11·0110082	·0007490637
1336	1 78 48 96	2 384 621 056	36·5513338	11·0137569	·0007485030
1337	1 78 75 69	2 389 979 753	36·5650106	11·0165041	·0007479432
1338	1 79 02 44	2 395 346 472	36·5786823	11·0192500	·0007473842
1339	1 79 29 21	2 400 721 219	36·5923489	11·0219945	·0007468260
1340	1 79 56 00	2 406 104 000	36·6060104	11·0247377	·0007462687
1341	1 79 82 81	2 411 494 821	36·6196668	11·0274795	·0007457122
1342	1 80 09 64	2 416 893 688	36·6333181	11·0302199	·0007451565
1343	1 80 36 49	2 422 300 607	36·6469644	11·0329590	·0007446016
1344	1 80 63 36	2 427 715 584	36·6606056	11·0356967	·0007440476
1345	1 80 90 25	2 433 138 625	36·6742416	11·0384330	·0007434944
1346	1 81 17 16	2 438 569 736	36·6878726	11·0411680	·0007429421
1347	1 81 44 09	2 444 008 923	36·7014986	11·0439017	·0007423905
1348	1 81 71 04	2 449 456 192	36·7151195	11·0466339	·0007418398
1349	1 81 98 01	2 454 911 549	36·7287353	11·0493649	·0007412898
1350	1 82 25 00	2 460 375 000	36·7423461	11·0520945	·0007407407
1351	1 82 52 01	2 465 846 551	36·7559519	11·0548227	·0007401924
1352	1 82 79 04	2 471 326 208	36·7695526	11·0575497	·0007396450
1353	1 83 06 09	2 476 813 977	36·7831483	11·0602752	·0007390983
1354	1 83 33 16	2 482 309 864	36·7967390	11·0629994	·0007385524
1355	1 83 60 25	2 487 813 875	36·8103246	11·0657222	·0007380074
1356	1 83 87 36	2 493 326 016	36·8239053	11·0684437	·0007374631
1357	1 84 14 49	2 498 846 293	36·8374809	11·0711639	·0007369197
1358	1 84 41 64	2 504 374 712	36·8510515	11·0738828	·0007363770
1359	1 84 68 81	2 509 911 279	36·8646172	11·0766003	·0007358352
1360	1 84 96 00	2 515 456 000	36·8781778	11·0793165	·0007352941
1361	1 85 23 21	2 521 008 881	36·8917335	11·0820314	·0007347539
1362	1 85 50 44	2 526 569 928	36·9052842	11·0847449	·0007342144
1363	1 85 77 69	2 532 139 147	36·9188299	11·0874571	·0007336757
1364	1 86 04 96	2 537 716 544	36·9323706	11·0901679	·0007331378
1365	1 86 32 25	2 543 302 125	36·9459064	11·0928775	·0007326007
1366	1 86 59 56	2 548 895 896	36·9594372	11·0955857	·0007320644
1367	1 86 86 89	2 554 497 863	36·9729631	11·0982926	·0007315289
1368	1 87 14 24	2 560 108 032	36·9864840	11·1009982	·0007309942

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1369	1 87 41 61	2 565 726 409	37·0000000	11·1037025	·0007304602
1370	1 87 69 00	2 571 353 000	37·0135110	11·1064054	·0007299270
1371	1 87 96 41	2 576 987 811	37·0270172	11·1091070	·0007293946
1372	1 88 23 84	2 582 630 848	37·0405184	11·1118073	·0007288630
1373	1 88 51 29	2 588 282 117	37·0540146	11·1145064	·0007283321
1374	1 88 78 76	2 593 941 624	37·0675060	11·1172041	·0007278020
1375	1 89 06 25	2 599 609 375	37·0809924	11·1199004	·0007272727
1376	1 89 33 76	2 605 285 376	37·0944740	11·1225955	·0007267442
1377	1 89 61 29	2 610 969 633	37·1079506	11·1252893	·0007262164
1378	1 89 88 84	2 616 662 152	37·1214224	11·1279817	·0007256894
1379	1 90 16 41	2 622 362 939	37·1348893	11·1306729	·0007251632
1380	1 90 44 00	2 628 072 000	37·1483512	11·1333628	·0007246377
1381	1 90 71 61	2 633 789 341	37·1618084	11·1360514	·0007241130
1382	1 90 99 24	2 639 514 968	37·1752606	11·1387386	·0007235890
1383	1 91 26 89	2 645 248 887	37·1887079	11·1414246	·0007230658
1384	1 91 54 56	2 650 991 104	37·2021505	11·1441093	·0007225434
1385	1 91 82 25	2 656 741 625	37·2155881	11·1467926	·0007220217
1386	1 92 09 96	2 662 500 456	37·2290209	11·1494747	·0007215007
1387	1 92 37 69	2 668 267 603	37·2424489	11·1521555	·0007209805
1388	1 92 65 44	2 674 043 072	37·2558720	11·1548350	·0007204611
1389	1 92 93 21	2 679 826 869	37·2692903	11·1575133	·0007199424
1390	1 93 21 00	2 685 619 000	37·2827037	11·1601903	·0007194245
1391	1 93 48 81	2 691 419 471	37·2961124	11·1628659	·0007189073
1392	1 93 76 64	2 697 228 288	37·3095162	11·1655403	·0007183908
1393	1 94 04 49	2 703 045 457	37·3229152	11·1682134	·0007178751
1394	1 94 32 36	2 708 870 984	37·3363094	11·1708852	·0007173601
1395	1 94 60 25	2 714 704 875	37·3496988	11·1735558	·0007168459
1396	1 94 88 16	2 720 547 136	37·3630834	11·1762250	·0007163324
1397	1 95 16 09	2 726 397 773	37·3764632	11·1788930	·0007158196
1398	1 95 44 04	2 732 256 792	37·3898382	11·1815598	·0007153076
1399	1 95 72 01	2 738 124 199	37·4032084	11·1842252	·0007147963
1400	1 96 00 00	2 744 000 000	37·4165738	11·1868894	·0007142857
1401	1 96 28 01	2 749 884 201	37·4299345	11·1895523	·0007137759
1402	1 96 56 04	2 755 776 808	37·4432904	11·1922139	·0007132668
1403	1 96 84 09	2 761 677 827	37·4566416	11·1948743	·0007127584
1404	1 97 12 16	2 767 587 264	37·4699880	11·1975334	0007122507
1405	1 97 40 25	2 773 505 125	37·4833296	11·2001913	·0007117438
1406	1 97 68 36	2 779 431 416	37·4966665	11·2028479	·0007112376
1407	1 97 96 49	2 785 366 143	37·5099987	11·2055032	·0007107321
1408	1 98 24 64	2 791 309 312	37·5233261	11·2081573	·0007102273
1409	1 98 52 81	2 797 260 929	37·5366487	11·2108101	·0007097232
1410	1 98 81 00	2 803 221 000	37·5499667	11·2134617	·0007092199
1411	1 99 09 21	2 809 189 531	37·5632799	11·2161120	·0007087172
1412	1 99 37 44	2 815 166 528	37·5765885	11·2187611	·0007082153
1413	1 99 65 69	2 821 151 997	37·5898922	11·2214089	·0007077141
1414	1 99 93 96	2 827 145 944	37·6031913	11·2240554	·0007072136
1415	2 00 22 25	2 833 148 375	37·6164857	11·2267007	·0007067138
1416	2 00 50 56	2 839 159 296	37·6297754	11·2293448	·0007062147
1417	2 00 78 89	2 845 178 713	37·6430604	11·2319876	·0007057163

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1418	2 01 07 24	2 851 206 632	37·6563407	11·2346292	·00070521
1419	2 01 35 61	2 857 243 059	37·6696164	11·2372696	·000704721
1420	2 01 64 00	2 863 288 000	37·6828874	11·2399087	·00070422
1421	2 01 92 41	2 869 341 461	37·6961536	11·2425465	·00070372
1422	2 02 20 84	2 875 403 448	37·7094153	11·2451831	·00070323
1423	2 02 49 29	2 881 473 967	37·7226722	11·2478185	·00070274
1424	2 02 77 76	2 887 553 024	37·7359245	11·2504527	·00070224
1425	2 03 06 25	2 893 640 625	37·7491722	11·2530856	·00070175
1426	2 03 34 76	2 899 736 776	37·7624152	11·2557173	·00070126
1427	2 03 63 29	2 905 841 483	37·7756535	11·2583478	·00070077
1428	2 03 91 84	2 911 954 752	37·7888873	11·2609770	·0007002801
1429	2 04 20 41	2 918 076 589	37·8021163	11·2636050	·0006997901
1430	2 04 49 00	2 924 207 000	37·8153408	11·2662318	·0006993007
1431	2 04 77 61	2 930 345 991	37·8285606	11·2688573	·0006988120
1432	2 05 06 24	2 936 493 568	37·8417759	11·2714816	·0006983240
1433	2 05 34 89	2 942 649 737	37·8549864	11·2741047	·0006978367
1434	2 05 63 56	2 948 814 504	37·8681924	11·2767266	·0006973501
1435	2 05 92 25	2 954 987 875	37·8813938	11·2793472	·0006968641
1436	2 06 20 96	2 961 169 856	37·8945906	11·2819666	·000696378
1437	2 06 49 69	2 967 360 453	37·9077828	11·2845849	·000695894
1438	2 06 78 44	2 973 559 672	37·9209704	11·2872019	·000695410
1439	2 07 07 21	2 979 767 519	37·9341535	11·2898177	·000694927
1440	2 07 36 00	2 985 984 000	37·9473319	11·2924323	·000694444
1441	2 07 64 81	2 992 209 121	37·9605058	11·2950457	·000693962
1442	2 07 93 64	2 998 442 888	37·9736751	11·2976579	·000693481
1443	2 08 22 49	3 004 685 307	37·9868398	11·3002688	·000693000
1444	2 08 51 36	3 010 936 384	38·0000000	11·3028786	·000692520
1445	2 08 80 25	3 017 196 125	38·0131556	11·3054871	·000692041
1446	2 09 09 16	3 023 464 536	38·0263067	11·3080945	·000691562
1447	2 09 38 09	3 029 741 623	38·0394532	11·3107006	·000691085
1448	2 09 67 04	3 036 027 392	38·0525952	11·3133056	·000690607
1449	2 09 96 01	3 042 321 849	38·0657326	11·3159094	·000690131
1450	2 10 25 00	3 048 625 000	38·0788655	11·3185119	·000689655
1451	2 10 54 01	3 054 936 851	38·0919939	11·3211132	·000689179
1452	2 10 83 04	3 061 257 408	38·1051178	11·3237134	·000688705
1453	2 11 12 09	3 067 586 677	38·1182371	11·3263124	·000688231
1454	2 11 41 16	3 073 924 664	38·1313519	11·3289102	·000687757
1455	2 11 70 25	3 080 271 375	38·1444622	11·3315067	·000687285
1456	2 11 99 36	3 086 626 816	38·1575681	11·3341022	·000686813
1457	2 12 28 49	3 092 990 993	38·1706693	11·3366964	·000686341
1458	2 12 57 64	3 099 363 912	38·1837662	11·3392894	·000685871
1459	2 12 86 81	3 105 745 579	38·1968585	11·3418813	·000685401
1460	2 13 16 00	3 112 136 000	38·2099463	11·3444719	·000684931
1461	2 13 45 21	3 118 535 181	38·2230297	11·3470614	·000684462
1462	2 13 74 44	3 124 943 128	38·2361085	11·3496497	·000683994
1463	2 14 03 69	3 131 359 847	38·2491829	11·3522368	·000683527
1464	2 14 32 96	3 137 785 344	38·2622529	11·3548227	·000683060
1465	2 14 62 25	3 144 219 625	38·2753184	11·3574075	·000682593
1466	2 14 91 56	3 150 662 696	38·2883794	11·3599911	·000682128

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1467	2 15 20 89	3 157 114 563	38·3014360	11·3625735	·0006816633
1468	2 15 50 24	3 163 575 232	38·3144881	11·3651547	·0006811989
1469	2 15 79 61	3 170 044 709	38·3275358	11·3677347	·0006807352
1470	2 16 09 00	3 176 523 000	38·3405790	11·3703136	·0006802721
1471	2 16 38 41	3 183 010 111	38·3536178	11·3728914	·0006798097
1472	2 16 67 84	3 189 506 048	38·3666522	11·3754679	·0006793478
1473	2 16 97 29	3 169 010 817	38·3796821	11·3780433	·0006788866
1474	2 17 26 76	3 202 524 424	38·3927076	11·3806175	·0006784261
1475	2 17 56 25	3 209 046 875	38·4057287	11·3831906	·0006779661
1476	2 17 85 76	3 215 578 176	38·4187454	11·3857625	·0006775068
1477	2 18 15 29	3 222 118 333	38·4317577	11·3883332	·0006770481
1478	2 18 44 84	3 228 667 352	38·4447656	11·3909028	·0006765900
1479	2 18 74 41	3 235 225 239	38·4577691	11·3934712	·0006761325
1480	2 19 04 00	3 241 792 000	38·4707681	11·3960384	·0006756757
1481	2 19 33 61	3 248 367 641	38·4837627	11·3986045	·0006752194
1482	2 19 63 24	3 254 952 168	38·4967530	11·4011695	·0006747638
1483	2 19 92 89	3 261 545 587	38·5097390	11·4037332	·0006743088
1484	2 20 22 56	3 268 147 904	38·5227206	11·4062959	·0006738544
1485	2 20 52 25	3 274 759 125	38·5356977	11·4088574	·0006734007
1486	2 20 81 96	3 281 379 256	38·5486705	11·4114177	·0006729475
1487	2 21 11 69	3 288 008 303	38·5616389	11·4139769	·0006724950
1488	2 21 41 44	3 294 646 272	38·5746030	11·4165349	·0006720430
1489	2 21 71 21	3 301 293 169	38·5875627	11·4190918	·0006715917
1490	2 22 01 00	3 307 949 000	38·6005181	11·4216476	·0006711409
1491	2 22 30 81	3 314 613 771	38·6134691	11·4242022	·0006706908
1492	2 22 60 64	3 321 287 488	38·6264158	11·4267556	·0006702413
1493	2 22 90 49	3 327 970 157	38·6393582	11·4293079	·0006697924
1494	2 23 20 36	3 334 661 784	38·6522962	11·4318591	·0006693440
1495	2 23 50 25	3 341 362 375	38·6652299	11·4344092	·0006688963
1496	2 23 80 16	3 348 071 936	38·6781593	11·4369581	·0006684492
1497	2 24 10 09	3 354 790 473	38·6910843	11·4395059	·0006680027
1498	2 24 40 04	3 361 517 992	38·7040050	11·4420525	·0006675567
1499	2 24 70 01	3 368 254 499	38·7169214	11·4445980	·0006671114
1500	2 25 00 00	3 375 000 000	38·7298335	11·4471424	·0006666667
1501	2 25 30 01	3 381 754 501	38·7427412	11·4496857	·0006662225
1502	2 25 60 04	3 388 518 008	38·7556447	11·4522278	·0006657790
1503	2 25 90 09	3 395 290 527	38·7685439	11·4547688	·0006643360
1504	2 26 20 16	3 402 072 064	38·7814389	11·4573087	·0006648936
1505	2 26 50 25	3 408 862 625	38·7943294	11·4598474	·0006644518
1506	2 26 80 36	3 415 662 216	38·8072158	11·4623850	·0006640106
1507	2 27 10 49	3 422 470 843	38·8200978	11·4649215	·0006635700
1508	2 27 40 64	3 429 288 512	38·8329757	11·4674568	·0006631300
1509	2 27 70 81	3 436 115 229	38·8458491	11·4699911	·0006626905
1510	2 28 01 00	3 442 951 000	38·8587184	11·4725242	·0006622517
1511	2 28 31 21	3 449 795 831	38·8715834	11·4750562	·0006618134
1512	2 28 61 44	3 456 649 728	38·8844442	11·4775871	·0006613757
1513	2 28 91 69	3 463 512 697	38·8973006	11·4801169	·0006609385
1514	2 29 21 96	3 470 384 744	38 9101529	11·4826455	·0006605020
1515	2 29 52 25	3 477 265 875	38·9230009	11·4851731	·0006600660

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1516	2 29 82 56	3 484 156 096	38·9358447	11·4876995	·0006596306
1517	2 30 12 89	3 491 055 413	38·9486841	11·4902249	·0006591958
1518	2 30 43 24	3 497 963 832	38·9615194	11·4927491	·0006587615
1519	2 30 73 61	3 504 881 359	38·9743505	11·4952722	·0006583278
1520	2 31 04 00	3 511 808 000	38·9871774	11·4977942	·0006578947
1521	2 31 34 41	3 518 743 761	39·0000000	11·5003151	·0006574622
1522	2 31 64 84	3 525 688 648	39·0128184	11·5028348	·0006570302
1523	2 31 95 29	3 532 642 667	39·0256326	11·5053535	·0006565988
1524	2 32 25 76	3 539 605 824	39·0384426	11·5078711	·0006561680
1525	2 32 56 25	3 546 578 125	39·0512483	11·5103876	·0006557377
1526	2 32 86 76	3 553 559 576	39·0640499	11·5129030	·0006553080
1527	2 33 17 29	3 560 550 183	39·0768473	11·5154173	·0006548788
1528	2 33 47 84	3 567 549 952	39·0896406	11·5179305	·0006544503
1529	2 33 78 41	3 574 558 889	39·1024296	11·5204425	·0006540222
1530	2 34 09 00	3 581 577 000	39·1152144	11·5229535	·0006535948
1531	2 34 39 61	3 588 604 291	39·1279951	11·5254634	·0006531679
1532	2 34 70 24	3 595 640 768	39·1407716	11·5279722	·0006527415
1533	2 35 00 89	3 602 686 437	39·1535439	11·5304799	·0006523157
1534	2 35 31 56	3 609 741 304	39·1663120	11·5329865	·0006518905
1535	2 35 62 25	3 616 805 375	39·1790760	11·5354920	·0006514658
1536	2 35 92 96	3 623 878 656	39·1918359	11·5379965	·0006510417
1537	2 36 23 69	3 630 961 153	39·2045915	11·5404998	·0006506181
1538	2 36 54 44	3 638 052 872	39·2173431	11·5430021	·0006501951
1539	2 36 85 21	3 645 153 819	39·2300905	11·5455033	·0006497726
1540	2 37 16 00	3 652 264 000	39·2428337	11·5480034	·0006493506
1541	2 37 46 81	3 659 383 421	39·2555728	11·5505025	·0006489293
1542	2 37 77 64	3 666 512 088	39·2683078	11·5530004	·0006485084
1543	2 38 08 49	3 673 650 007	39·2810387	11·5554973	·0006480881
1544	2 38 39 36	3 680 797 184	39·2937654	11·5579931	·0006476684
1545	2 38 70 25	3 687 953 625	39·3064880	11·5604878	·0006472492
1546	2 39 01 16	3 695 119 336	39·3192065	11·5629815	·0006468305
1547	2 39 32 09	3 702 294 323	39·3319208	11·5654740	·0006464124
1548	2 39 63 04	3 709 478 592	39·3446311	11·5679655	·0006459948
1549	2 39 94 01	3 716 672 149	39·3573373	11·5704559	·0006455778
1550	2 40 25 00	3 723 875 000	39·3700394	11·5729453	·0006451613
1551	2 40 56 01	3 731 087 151	39·3827373	11·5754336	·0006447453
1552	2 40 87 04	3 738 308 608	39·3954312	11·5779208	·0006443299
1553	2 41 18 09	3 745 539 377	39·4081210	11·5804069	·0006439150
1554	2 41 49 16	3 752 779 464	39·4208067	11·5828919	·0006435006
1555	2 41 80 25	3 760 028 875	39·4334883	11·5853759	·0006430868
1556	2 42 11 36	3 767 287 616	39·4461658	11·5878588	·0006426735
1557	2 42 42 49	3 774 555 693	39·4588393	11·5903407	·0006422608
1558	2 42 73 64	3 781 833 112	39·4715087	11·5928215	·0006418485
1559	2 43 04 81	3 789 119 879	39·4841740	11·5953013	·0006414368
1560	2 43 36 00	3 796 416 000	39·4968353	11·5977799	·0006410256
1561	2 43 67 21	3 803 721 481	39·5094925	11·6002576	·0006406150
1562	2 43 98 44	3 811 036 328	39·5221457	11·6027342	·0006402049
1563	2 44 29 69	3 818 360 547	39·5347948	11·6052097	·0006397953
1564	2 44 60 96	3 825 694 144	39·5474399	11·6076841	·0006393862

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1565	2 44 92 25	3 833 037 125	39·5600809	11·6101575	·0006389776
1566	2 45 23 56	3 840 389 496	39·5727179	11·6126299	·0006385696
1567	2 45 54 89	3 847 751 263	39·5853508	11·6151012	·0006381621
1568	2 45 86 24	3 855 123 432	39·5979797	11·6175715	·0006377551
1569	2 46 17 61	3 862 503 009	39·6106046	11·6200407	·0006373486
1570	2 46 49 00	3 869 893 000	39·6232255	11·6225088	·0006369427
1571	2 46 80 41	3 877 292 411	39·6358424	11·6249759	·0006365372
1572	2 47 11 84	3 884 701 248	39·6484552	11·6274420	·0006361323
1573	2 47 43 29	3 892 119 517	39·6610640	11·6299070	·0006357279
1574	2 47 74 76	3 899 547 224	39·6736688	11·6323710	·0006353240
1575	2 48 06 25	3 906 984 375	39·6862696	11·6348339	·0006349206
1576	2 48 37 76	3 914 430 976	39·6988665	11·6372957	·0006345178
1577	2 48 69 29	3 921 887 033	39·7114593	11·6397566	·0006341154
1578	2 49 00 84	3 929 352 552	39·7240481	11·6422164	·0006337136
1579	2 49 32 41	3 936 827 539	39·7366329	11·6446751	·0006333122
1580	2 49 64 00	3 944 312 000	39·7492138	11·6471329	·0006329114
1581	2 49 95 61	3 951 805 941	39·7617907	11·6495895	·0006325111
1582	2 50 27 24	3 959 309 368	39·7743636	11·6520452	·0006321113
1583	2 50 58 89	3 966 822 287	39·7869325	11·6544998	·0006317119
1584	2 50 90 56	3 974 344 704	39·7994975	11·6569534	·0006313131
1585	2 51 22 25	3 981 876 625	39·8120585	11·6594059	·0006309148
1586	2 51 53 96	3 989 418 056	39·8246155	11·6618574	·0006305170
1587	2 51 85 69	3 996 969 003	39·8371686	11·6643079	·0006301197
1588	2 52 17 44	4 004 529 472	39·8497177	11·6667574	·0006297229
1589	2 52 49 21	4 012 099 469	39·8622628	11·6692058	·0006293266
1590	2 52 81 00	4 019 679 000	39·8748040	11·6716532	·0006289308
1591	2 53 12 81	4 027 268 071	39·8873413	11·6740996	·0006285355
1592	2 53 44 64	4 034 866 688	39·8998747	11·6765449	·0006281407
1593	2 53 76 49	4 042 474 857	39·9124041	11·6789892	·0006277464
1594	2 54 08 36	4 050 092 584	39·9249295	11·6814325	·0006273526
1595	2 54 40 25	4 057 719 875	39·9374511	11·6838748	·0006269592
1596	2 54 72 16	4 065 356 736	39·9499687	11·6863161	·0006265664
1597	2 55 04 09	4 073 003 173	39·9624824	11·6887563	·0006261741
1598	2 55 36 04	4 080 659 192	39·9749922	11·6911955	·0006257822
1599	2 55 68 01	4 088 324 799	39·9874980	11·6936337	·0006253909
1600	2 56 00 00	4 096 000 000	40·0000000	11·6960709	·0006250000
1601	2 56 32 01	4 103 684 801	40·0124980	11·6985071	·0006246096
1602	2 56 64 04	4 111 379 208	40·0249922	11·7009422	·0006242197
1603	2 56 96 09	4 119 083 227	40·0374824	11·7033764	·0006238303
1604	2 57 28 16	4 126 796 864	40·0499688	11·7058095	·0006234414
1605	2 57 60 25	4 134 520 125	40·0624512	11·7082417	·0006230530
1606	2 57 92 36	4 142 253 016	40·0749298	11·7106728	·0006226650
1607	2 58 24 49	4 149 995 543	40·0874045	11·7131029	·0006222775
1608	2 58 56 64	4 157 747 712	40·0998753	11·7155320	·0006218905
1609	2 58 88 81	4 165 509 529	40·1123423	11·7179601	·0006215040
1610	2 59 21 00	4 173 281 000	40·1248053	11·7203872	·0006211180
1611	2 59 53 21	4 181 062 131	40·1372645	11·7228133	·0006207325
1612	2 59 85 44	4 188 852 928	40·1497198	11·7252384	·0006203474
1613	2 60 17 69	4 196 653 397	40·1621713	11·7276625	·0006199628

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1614	2 60 49 96	4 204 463 544	40·1746188	11·7300855	·0006195787
1615	2 60 82 25	4 212 283 375	40·1870626	11·7325076	·0006191950
1616	2 61 14 56	4 220 112 896	40·1995025	11·7349286	·0006188119
1617	2 61 46 89	4 227 952 113	40·2119385	11·7373487	·0006184292
1618	2 61 79 24	4 235 801 032	40·2243707	11·7397677	·0006180470
1619	2 62 11 61	4 243 659 659	40·2367990	11·7421858	·0006176652
1620	2 62 44 00	4 251 528 000	40·2492236	11·7446029	·0006172840
1621	2 62 76 41	4 259 406 061	40·2616443	11·7470190	·0006169031
1622	2 63 08 84	4 267 293 848	40·2740611	11·7494341	·0006165228
1623	2 63 41 29	4 275 191 367	40·2864742	11·7518482	·0006161429
1624	2 63 73 76	4 283 098 624	40·2988834	11·7542613	·0006157635
1625	2 64 06 25	4 291 015 625	40·3112888	11·7566734	·0006153846
1626	2 64 38 76	4 298 942 376	40·3236903	11·7590846	·0006150062
1627	2 64 71 29	4 306 878 883	40·3360881	11·7614947	·0006146282
1628	2 65 03 84	4 314 825 152	40·3484820	11·7639039	·0006142506
1629	2 65 36 41	4 322 781 189	40·3608721	11·7663121	·0006138735
1630	2 65 69 00	4 330 747 000	40·3732585	11·7687193	·0006134969
1631	2 66 01 61	4 338 722 591	40·3856410	11·7711255	·0006131208
1632	2 66 34 24	4 346 707 968	40·3980198	11·7735306	·0006127451
1633	2 66 66 89	4 354 703 137	40·4103947	11·7759349	·0006123699
1634	2 66 99 56	4 362 708 104	40·4227658	11·7783381	·0006119951
1635	2 67 32 25	4 370 722 875	40·4351332	11·7807404	·0006116208
1636	2 67 64 96	4 378 747 456	40·4474968	11·7831417	·0006112469
1637	2 67 97 69	4 386 781 853	40·4598566	11·7855420	·0006108735
1638	2 68 30 44	4 394 826 072	40·4722127	11·7879414	·0006105006
1639	2 68 63 21	4 402 880 119	40·4845649	11·7903397	·0006101281
1640	2 68 96 00	4 410 944 000	40·4969135	11·7927371	·0006097561
1641	2 69 28 81	4 419 017 721	40·5092582	11·7951335	·0006093845
1642	2 69 61 64	4 427 101 288	40·5215992	11·7975289	·0006090134
1643	2 69 94 49	4 435 194 707	40·5339364	11·7999234	·0006086427
1644	2 70 27 36	4 443 297 984	40·5462699	11·8023169	·0006082725
1645	2 70 60 25	4 451 411 125	40·5585996	11·8047094	·0006079027
1646	2 70 93 16	4 459 534 136	40·5709255	11·8071010	·0006075334
1647	2 71 26 09	4 467 667 023	40·5832477	11·8094916	·0006071645
1648	2 71 59 04	4 475 809 792	40·5955663	11·8118812	·0006067961
1649	2 71 92 01	4 483 962 449	40·6078810	11·8142698	·0006064281
1650	2 72 25 00	4 492 125 000	40·6201920	11·8166576	·0006060606
1651	2 72 58 01	4 500 297 451	40·6324993	11·8190443	·0006056935
1652	2 72 91 04	4 508 479 808	40·6448029	11·8214301	·0006053269
1653	2 73 24 09	4 516 672 077	40·6571027	11·8238149	·0006049607
1654	2 73 57 16	4 524 874 264	40·6693988	11·8261987	·0006045949
1655	2 73 90 25	4 533 086 375	40·6816912	11·8285816	·0006042296
1656	2 74 23 36	4 541 308 416	40·6939799	11·8309634	·0006038647
1657	2 74 56 49	4 549 540 393	40·7062648	11·8333444	·0006035003
1658	2 74 89 64	4 557 782 312	40·7185461	11·8357244	·0006031363
1659	2 75 22 81	4 566 034 179	40·7308237	11·8381034	·0006027728
1660	2 75 56 00	4 574 296 000	40·7430976	11·8404815	·0006024096
1661	2 75 89 21	4 582 567 781	40·7553677	11·8428586	·0006020470
1662	2 76 22 44	4 590 849 528	40·7676342	11·8452348	·0006016847

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1663	2 76 55 69	4 599 141 247	40·7798970	11·8476100	·0006013229
1664	2 76 88 96	4 607 442 944	40·7921561	11·8499843	·0006009615
1665	2 77 22 25	4 615 754 625	40·8044115	11·8523576	·0006006006
1666	2 77 55 56	4 624 076 296	40·8166633	11·8547299	·0006002401
1667	2 77 88 89	4 632 407 963	40·8289113	11·8571014	·0005998800
1668	2 78 22 24	4 640 749 632	40·8411557	11·8594719	·0005995204
1669	2 78 55 61	4 649 101 309	40·8533964	11·8618414	·0005991612
1670	2 78 89 00	4 657 463 000	40·8656335	11·8642100	·0005988024
1671	2 79 22 41	4 665 834 711	40·8778669	11·8665776	·0005984440
1672	2 79 55 84	4 674 216 448	40·8900966	11·8689443	·0005980861
1673	2 79 89 29	4 682 608 217	40·9023227	11·8713100	·0005977286
1674	2 80 22 76	4 691 010 024	40·9145451	11·8736748	·0005973716
1675	2 80 56 25	4 699 421 875	40·9267638	11·8760387	·0005970149
1676	2 80 89 76	4 707 843 776	40·9389790	11·8784016	·0005966587
1677	2 81 23 29	4 716 275 733	40·9511905	11·8807636	·0005963029
1678	2 81 56 84	4 724 717 752	40·9633983	11·8831246	·0005959476
1679	2 81 90 41	4 733 169 839	40·9756025	11·8854847	·0005955926
1680	2 82 24 00	4 741 632 000	40·9878031	11·8878439	·0005952381
1681	2 82 57 61	4 750 104 241	41·0000000	11·8902022	·0005948840
1682	2 82 91 24	4 758 586 568	41·0121933	11·8925595	·0005945303
1683	2 83 24 89	4 767 078 987	41·0243830	11·8949159	·0005941771
1684	2 83 58 56	4 775 581 504	41·0365691	11·8972713	·0005938242
1685	2 83 92 25	4 784 094 125	41·0487515	11·8996258	·0005934718
1686	2 84 25 96	4 792 616 856	41·0609303	11·9019793	·0005931198
1687	2 84 59 69	4 801 149 703	41·0731055	11·9043319	·0005927682
1688	2 84 93 44	4 809 692 672	41·0852772	11·9066836	·0005924171
1689	2 85 27 21	4 818 245 769	41·0974452	11·9090344	·0005920663
1690	2 85 61 00	4 826 809 000	41·1096096	11·9113843	·0005917160
1691	2 85 94 81	4 835 382 371	41·1217704	11·9137332	·0005913661
1692	2 86 28 64	4 843 965 888	41·1339276	11·9160812	·0005910165
1693	2 86 62 49	4 852 559 557	41·1460812	11·9184283	·0005906675
1694	2 86 96 36	4 861 163 384	41·1582313	11·9207744	·0005903188
1695	2 87 30 25	4 869 777 375	41·1703777	11·9231196	·0005899705
1696	2 87 64 16	4 878 401 536	41·1825206	11·9254639	·0005896226
1697	2 87 98 09	4 887 035 873	41·1946599	11·9278073	·0005892752
1698	2 88 32 04	4 895 680 392	41·2067956	11·9301497	·0005889282
1699	2 88 66 01	4 904 335 099	41·2189277	11·9324913	·0005885815
1700	2 89 00 00	4 913 000 000	41·2310563	11·9348319	·0005882353
1701	2 89 34 01	4 921 675 101	41·2431812	11·9371716	·0005878895
1702	2 89 68 04	4 930 360 408	41·2553027	11·9395104	·0005875441
1703	2 90 02 09	4 939 055 927	41·2674205	11·9418482	·0005871991
1704	2 90 36 16	4 947 761 664	41·2795349	11·9441852	·0005868545
1705	2 90 70 25	4 956 477 625	41·2916456	11·9465213	·0005865103
1706	2 91 04 36	4 965 203 816	41·3037529	11·9488564	·0005861665
1707	2 91 38 49	4 973 940 243	41·3158565	11·9511906	·0005858231
1708	2 91 72 64	4 982 686 912	41·3279566	11·9535239	·0005854801
1709	2 92 06 81	4 991 443 829	41·3400532	11·9558563	·0005851375
1710	2 92 41 00	5 000 211 000	41·3521463	11·9581878	·0005847953
1711	2 92 75 21	5 008 988 431	41·3642358	11·9605184	·0005844535

No.	Square	Cube	Square Root	Cube Root	Reciprocal
712	2 93 09 44	5 017 776 128	41·3763217	11·9628481	·0005841121
713	2 93 43 69	5 026 574 097	41·3884042	11·9651768	·0005837712
714	2 93 77 96	5 035 382 344	41·4004831	11·9675047	·0005834306
715	2 94 12 25	5 044 200 875	41·4125585	11·9698317	·0005830904
716	2 94 46 56	5 053 029 696	41·4246304	11·9721577	·0005827506
717	2 94 80 89	5 061 868 813	41·4366987	11·9744829	·0005824112
718	2 95 15 24	5 070 718 232	41·4487636	11·9768071	·0005820722
719	2 95 49 61	5 079 577 959	41·4608249	11·9791304	·0005817336
720	2 95 84 00	5 088 448 000	41·4728827	11·9814528	·0005813953
721	2 96 18 41	5 097 328 361	41·4849370	11·9837744	·0005810575
722	2 96 52 84	5 106 219 048	41·4969878	11·9860950	·0005807201
723	2 96 87 29	5 115 120 067	41·5090351	11·9884148	·0005803831
724	2 97 21 76	5 124 031 424	41·5210790	11·9907336	·0005800464
725	2 97 56 25	5 132 953 125	41·5331193	11·9930516	·0005797101
726	2 97 90 76	5 141 885 176	41·5451561	11·9953686	·0005793743
727	2 98 25 29	5 150 827 583	41·5571895	11·9976848	·0005790388
728	2 98 59 84	5 159 780 352	41·5692194	12·0000000	·0005787037
729	2 98 94 41	5 168 743 489	41·5812457	12·0023144	·0005783690
730	2 99 29 00	5 177 717 000	41·5932686	12·0046278	·0005780347
731	2 99 63 61	5 186 700 891	41·6052881	12·0069404	·0005777008
732	2 99 98 24	5 195 695 168	41·6173041	12·0092521	·0005773672
733	3 00 32 89	5 204 699 837	41·6293166	12·0115629	·0005770340
734	3 00 67 56	5 213 714 904	41·6413256	12·0138728	·0005767013
735	3 01 02 25	5 222 740 375	41·6533312	12·0161818	·0005763689
736	3 01 36 96	5 231 776 256	41·6653333	12·0184900	·0005760369
737	3 01 71 69	5 240 822 553	41·6773319	12·0207973	·0005757052
738	3 02 06 44	5 249 879 272	41·6893271	12·0231037	·0005753740
739	3 02 41 21	5 258 946 419	41·7013189	12·0254092	·0005750431
740	3 02 76 00	5 268 024 000	41·7133072	12·0277138	·0005747126
741	3 03 10 81	5 277 112 021	41·7252921	12·0300175	·0005743825
742	3 03 45 64	5 286 210 488	41·7372735	12·0323204	·0005740528
743	3 03 80 49	5 295 319 407	41·7492515	12·0346223	·0005737235
744	3 04 15 36	5 304 438 784	41·7612260	12·0369233	·0005733945
745	3 04 50 25	5 313 568 625	41·7731971	12·0392235	·0005730659
746	3 04 85 16	5 322 708 936	41·7851648	12·0415229	·0005727377
747	3 05 20 09	5 331 859 723	41·7971291	12·0438213	·0005724098
748	3 05 55 04	5 341 020 992	41·8090899	12·0461189	·0005720824
749	3 05 90 01	5 350 192 749	41·8210473	12·0484156	·0005717553
750	3 06 25 00	5 359 375 000	41·8330013	12·0507114	·0005714286
751	3 06 60 01	5 368 567 751	41·8449519	12·0530063	·0005711022
752	3 06 95 04	5 377 771 008	41·8568991	12·0553003	·0005707763
753	3 07 30 09	5 386 984 777	41·8688428	12·0575935	·0005704507
754	3 07 65 16	5 396 209 064	41·8807832	12·0598859	·0005701254
755	3 08 00 25	5 405 443 875	41·8927201	12·0621773	·0005698006
756	3 08 35 36	5 414 689 216	41·9046537	12·0644679	·0005694761
757	3 08 70 49	5 423 945 093	41·9165838	12·0667576	·0005691520
758	3 09 05 64	5 433 211 512	41·9285106	12·0690464	·0005688282
759	3 09 40 81	5 442 488 479	41·9404339	12·0713344	·0005685048
760	3 09 76 00	5 451 776 000	41·9523539	12·0736215	·0005681818

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1761	3 10 11 21	5 461 074 081	41·9642705	12·0759077	·0005678592
1762	3 10 46 44	5 470 382 728	41·9761837	12·0781930	·0005675369
1763	3 10 81 69	5 479 701 947	41·9880935	12·0804775	·0005672150
1764	3 11 16 96	5 489 031 744	42·0000000	12·0827612	·0005668934
1765	3 11 52 25	5 498 372 125	42·0119031	12·0850439	·0005665722
1766	3 11 87 56	5 507 723 096	42·0238028	12·0873258	·0005662514
1767	3 12 22 89	5 517 084 663	42·0356991	12·0896069	·0005659310
1768	3 12 58 24	5 526 456 832	42·0475921	12·0918870	·0005656109
1769	3 12 93 61	5 535 839 609	42·0594817	12·0941664	·0005652911
1770	3 13 29 00	5 545 233 000	42·0713679	12·0964449	·0005649718
1771	3 13 64 41	5 554 637 011	42·0832508	12·0987226	·0005646527
1772	3 13 99 84	5 564 051 648	42·0951304	12·1009993	·0005643341
1773	3 14 35 29	5 573 476 917	42·1070065	12·1032753	·0005640158
1774	3 14 70 76	5 582 912 824	42·1188794	12·1055503	·0005636979
1775	3 15 06 25	5 592 359 375	42·1307488	12·1078245	·0005633803
1776	3 15 41 76	5 601 816 576	42·1426150	12·1100979	·0005630631
1777	3 15 77 29	5 611 284 433	42·1544778	12·1123704	·0005627462
1778	3 16 12 84	5 620 762 952	42·1663373	12·1146420	·0005624297
1779	3 16 48 41	5 630 252 139	42·1781934	12·1169128	·0005621135
1780	3 16 84 00	5 639 752 000	42·1900462	12·1191827	·0005617978
1781	3 17 19 61	5 649 262 541	42·2018957	12·1214518	·0005614823
1782	3 17 55 24	5 658 783 768	42·2137418	12·1237200	·0005611672
1783	3 17 90 89	5 668 315 687	42·2255846	12·1259874	·0005608525
1784	3 18 26 56	5 677 858 304	42·2374242	12·1282539	·0005605381
1785	3 18 62 25	5 687 411 625	42·2492603	12·1305197	·0005602241
1786	3 18 97 96	5 696 975 656	42·2610932	12·1327845	·0005599104
1787	3 19 33 69	5 706 550 403	42·2729227	12·1350485	·0005595971
1788	3 19 69 44	5 716 135 872	42·2847490	12·1373117	·0005592841
1789	3 20 05 21	5 725 732 069	42·2965719	12·1395740	·0005589715
1790	3 20 41 00	5 735 339 000	42·3083916	12·1418355	·0005586592
1791	3 20 76 81	5 744 956 671	42·3202079	12·1440961	·0005583473
1792	3 21 12 64	5 754 585 088	42·3320210	12·1463559	·0005580357
1793	3 21 48 49	5 764 224 257	42·3438307	12·1486148	·0005577245
1794	3 21 84 36	5 773 874 184	42·3556371	12·1508729	·0005574136
1795	3 22 20 25	5 783 534 875	42·3674403	12·1531302	·0005571031
1796	3 22 56 16	5 793 206 336	42·3792402	12·1553866	·0005567929
1797	3 22 92 09	5 802 888 573	42·3910368	12·1576422	·0005564830
1798	3 23 28 04	5 812 581 592	42·4028301	12·1598970	·0005561735
1799	3 23 64 01	5 822 285 399	42·4146201	12·1621509	·0005558644
1800	3 24 00 00	5 832 000 000	42·4264069	12·1644040	·0005555556
1801	3 24 36 01	5 841 725 401	42·4381903	12·1666562	·0005552471
1802	3 24 72 04	5 851 461 608	42·4499705	12·1689076	·0005549390
1803	3 25 08 09	5 861 208 627	42·4617475	12·1711582	·0005546312
1804	3 25 44 16	5 870 966 464	42·4735212	12·1734079	·0005543237
1805	3 25 80 25	5 880 735 125	42·4852916	12·1756569	·0005540166
1806	3 26 16 36	5 890 514 616	42·4970587	12·1779050	·0005537099
1807	3 26 52 49	5 900 304 943	42·5088226	12·1801522	·0005534034
1808	3 26 88 64	5 910 106 112	42·5205833	12·1823987	·0005530973
1809	3 27 24 81	5 919 918 129	42·5323406	12·1846443	·0005527916

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1810	3 27 61 00	5 929 741 000	42·5440948	12·1868891	·0005524862
1811	3 27 97 21	5 939 574 731	42·5558456	12·1891331	·0005521811
1812	3 28 33 44	5 949 419 328	42·5675933	12·1913762	·0005518764
1813	3 28 69 69	5 959 274 797	42·5793377	12·1936185	·0005515720
1814	3 29 05 96	5 969 141 144	42·5910789	12·1958599	·0005512679
1815	3 29 42 25	5 979 018 375	42·6028168	12·1981006	·0005509642
1816	3 29 78 56	5 988 906 496	42·6145515	12·2003404	·0005506608
1817	3 30 14 89	5 998 805 513	42·6262829	12·2025794	·0005503577
1818	3 30 51 24	6 008 715 432	42·6380112	12·2048176	·0005500550
1819	3 30 87 61	6 018 636 259	42·6497362	12·2070549	·0005497526
1820	3 31 24 00	6 028 568 000	42·6614580	12·2092915	·0005494505
1821	3 31 60 41	6 038 510 661	42·6731766	12·2115272	·0005491488
1822	3 31 96 84	6 048 464 248	42·6848919	12·2137621	·0005488474
1823	3 32 33 29	6 058 428 767	42·6966040	12·2159962	·0005485464
1824	3 32 69 76	6 068 404 224	42·7083130	12·2182295	·0005482456
1825	3 33 06 25	6 078 390 625	42·7200187	12·2204620	·0005479452
1826	3 33 42 76	6 088 387 976	42·7317212	12·2226936	·0005476451
1827	3 33 79 29	6 098 396 283	42·7434206	12·2249244	·0005473454
1828	3 34 15 84	6 108 415 552	42·7551167	12·2271544	·0005470460
1829	3 34 52 41	6 118 445 789	42·7668095	12·2293836	·0005467469
1830	3 34 89 00	6 128 487 000	42·7784992	12·2316120	·0005464481
1831	3 35 25 61	6 138 539 191	42·7901858	12·2338396	·0005461496
1832	3 35 62 24	6 148 602 368	42·8018691	12·2360663	·0005458515
1833	3 35 98 89	6 158 676 537	42·8135492	12·2382923	·0005455537
1834	3 36 35 56	6 168 761 704	42·8252262	12·2405174	·0005452563
1835	3 36 72 25	6 178 857 875	42·8368999	12·2427418	·0005449591
1836	3 37 08 96	6 188 965 056	42·8485706	12·2449653	·0005446623
1837	3 37 45 69	6 199 083 253	42·8602380	12·2471880	·0005443658
1838	3 37 82 44	6 209 212 472	42·8719022	12·2494099	·0005440696
1839	3 38 19 21	6 219 352 719	42·8835633	12·2516310	·0005437738
1840	3 38 56 00	6 229 504 000	42·8952212	12·2538513	·0005434783
1841	3 38 92 81	6 239 666 321	42·9068759	12·2560708	·0005431831
1842	3 39 29 64	6 249 839 688	42·9185275	12·2582895	·0005428882
1843	3 39 66 49	6 260 024 107	42·9301759	12·2605074	·0005425936
1844	3 40 03 36	6 270 219 584	42·9418211	12·2627245	·0005422993
1845	3 40 40 25	6 280 426 125	42·9534632	12·2649408	·0005420054
1846	3 40 77 16	6 290 643 736	42·9651021	12·2671563	·0005417118
1847	3 41 14 09	6 300 872 423	42·9767379	12·2693710	·0005414185
1848	3 41 51 04	6 311 112 192	42·9883705	12·2715849	·0005411255
1849	3 41 88 01	6 321 363 049	43·0000000	12·2737980	·0005408329
1850	3 42 25 00	6 331 625 000	43·0116263	12·2760103	·0005405405
1851	3 42 62 01	6 341 898 051	43·0232495	12·2782218	·0005402485
1852	3 42 99 04	6 352 182 208	43·0348696	12·2804325	·0005399568
1853	3 43 36 09	6 362 477 477	43·0464865	12·2826424	·0005396654
1854	3 43 73 16	6 372 783 864	43·0581003	12·2848515	·0005393743
1855	3 44 10 25	6 383 101 375	43·0697109	12·2870598	·0005390836
1856	3 44 47 36	6 393 430 016	43·0813185	12·2892673	·0005387931
1857	3 44 84 49	6 403 769 793	43·0929228	12·2914740	·0005385030
1858	3 45 21 64	6 414 120 712	43·1045241	12·2936800	·0005382131

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1859	3 45 58 81	6 424 482 779	43·1161223	12·2958851	·0005379236
1860	3 45 96 00	6 434 856 000	43·1277173	12·2980895	·0005376344
1861	3 46 33 21	6 445 240 381	43·1393092	12·3002930	·0005373455
1862	3 46 70 44	6 455 635 928	43·1508980	12·3024958	·0005370569
1863	3 47 07 69	6 466 042 647	43·1624837	12·3046978	·0005367687
1864	3 47 44 96	6 476 460 544	43·1740663	12·3068990	·0005364807
1865	3 47 82 25	6 486 889 625	43·1856458	12·3090994	·0005361930
1866	3 48 19 56	6 497 329 896	43·1972221	12·3112991	·0005359057
1867	3 48 56 89	6 507 781 363	43·2087954	12·3134979	·0005356186
1868	3 48 94 24	6 518 244 032	43·2203656	12·3156959	·0005353319
1869	3 49 31 61	6 528 717 909	43·2319326	12·3178932	·0005350455
1870	3 49 69 00	6 539 203 000	43·2434966	12·3200897	·0005347594
1871	3 50 06 41	6 549 699 311	43·2550575	12·3222854	·0005344735
1872	3 50 43 84	6 560 206 848	43·2666153	12·3244803	·0005341880
1873	3 50 81 29	6 570 725 617	43·2781700	12·3266744	·0005339028
1874	3 51 18 76	6 581 255 624	43·2897216	12·3288678	·0005336179
1875	3 51 56 25	6 591 796 875	43·3012702	12·3310604	·0005333333
1876	3 51 93 76	6 602 349 376	43·3128157	12·3332522	·0005330490
1877	3 52 31 29	6 612 913 133	43·3243580	12·3354432	·0005327651
1878	3 52 68 84	6 623 488 152	43·3358973	12·3376334	·0005324814
1879	3 53 06 41	6 634 074 439	43·3474336	12·3398229	·0005321980
1880	3 53 44 00	6 644 672 000	43·3589668	12·3420116	·0005319149
1881	3 53 81 61	6 655 280 841	43·3704969	12·3441995	·0005316321
1882	3 54 19 24	6 665 900 968	43·3820239	12·3463866	·0005313496
1883	3 54 56 89	6 676 532 387	43·3935479	12·3485730	·0005310674
1884	3 54 94 56	6 687 175 104	43·4050688	12·3507586	·0005307856
1885	3 55 32 25	6 697 829 125	43·4165867	12·3529434	·0005305040
1886	3 55 69 96	6 708 494 456	43·4281015	12·3551274	·0005302227
1887	3 56 07 69	6 719 171 103	43·4396132	12·3573107	·0005299417
1888	3 56 45 44	6 729 859 072	43·4511220	12·3594932	·0005296610
1889	3 56 83 21	6 740 558 369	43·4626276	12·3616749	·0005293806
1890	3 57 21 00	6 751 269 000	43·4741302	12·3638559	·0005291005
1891	3 57 58 81	6 761 990 971	43·4856298	12·3660361	·0005288207
1892	3 57 96 64	6 772 724 288	43·4971263	12·3682155	·0005285412
1893	3 58 34 49	6 783 468 957	43·5086198	12·3703941	·0005282620
1894	3 58 72 36	6 794 224 984	43·5201103	12·3725721	·0005279831
1895	3 59 10 25	6 804 992 375	43·5315977	12·3747492	·0005277045
1896	3 59 48 16	6 815 771 136	43·5430821	12·3769255	·0005274262
1897	3 59 86 09	6 826 561 273	43·5545635	12·3791011	·0005271481
1898	3 60 24 04	6 837 362 792	43·5660418	12·3812759	·0005268704
1899	3 60 62 01	6 848 175 699	43·5775171	12·3834500	·0005265929
1900	3 61 00 00	6 859 000 000	43·5889894	12·3856233	·0005263158
1901	3 61 38 01	6 869 835 701	43·6004587	12·3877959	·0005260389
1902	3 61 76 04	6 880 682 808	43·6119249	12·3899676	·0005257624
1903	3 62 14 09	6 891 541 327	43·6233882	12·3921386	·0005254861
1904	3 62 52 16	6 902 411 264	43·6348485	12·3943089	·0005252101
1905	3 62 90 25	6 913 292 625	43·6463057	12·3964784	·0005249344
1906	3 63 28 36	6 924 185 416	43·6577599	12·3986471	·0005246590
1907	3 63 66 49	6 935 089 643	43·6692111	12·4008151	·0005243838

Square	Cube	Square Root	Cube Root	Reciprocal
64 04 64	6 946 005 312	43·6806593	12·4029823	·0005241090
64 42 81	6 956 932 429	43·6921045	12·4051488	·0005238345
64 81 00	6 967 871 000	43·7035467	12·4073145	·0005235602
65 19 21	6 978 821 031	43·7149860	12·4094794	·0005232862
65 57 44	6 989 782 528	43·7264222	12·4116436	·0005230126
65 95 69	7 000 755 497	43·7378554	12·4138070	·0005227392
66 33 96	7 011 739 944	43·7492857	12·4159697	·0005224660
66 72 25	7 022 735 875	43·7607129	12·4181316	·0005221932
3 67 10 56	7 033 743 296	43·7721373	12·4202928	·0005219207
3 67 48 89	7 044 762 213	43·7835585	12·4224533	·0005216484
3 67 87 24	7 055 792 632	43·7949768	12·4246129	·0005213764
3 68 25 61	7 066 834 559	43·8063922	12·4267719	·0005211047
3 68 64 00	7 077 888 000	43·8178046	12·4289300	·0005208333
3 69 02 41	7 088 952 961	43·8292140	12·4310875	·0005205622
3 69 40 84	7 100 029 448	43·8406204	12·4332441	·0005202914
3 69 79 29	7 111 117 467	43·8520239	12·4354001	·0005200208
3 70 17 76	7 122 217 024	43·8634244	12·4375552	·0005197505
3 70 56 25	7 133 328 125	43·8748219	12·4397097	·0005194805
3 70 94 76	7 144 450 776	43·8862165	12·4418634	·0005192108
3 71 33 29	7 155 584 983	43·8976081	12·4440163	·0005189414
3 71 71 84	7 166 730 752	43·9089968	12·4461685	·0005186722
3 72 10 41	7 177 888 089	43·9203825	12·4483200	·0005184033
3 72 49 00	7 189 057 000	43·9317652	12·4504707	·0005181347
3 72 87 61	7 200 237 491	43·9431451	12·4526206	·0005178664
3 73 26 24	7 211 429 568	43·9545220	12·4547699	·0005175983
3 73 64 89	7 222 633 237	43·9658959	12·4569184	·0005173306
3 74 03 56	7 233 848 504	43·9772668	12·4590661	·0005170631
3 74 42 25	7 245 075 375	43·9886349	12·4612131	·0005167959
3 74 80 96	7 256 313 856	44·0000000	12·4633594	·0005165289
3 75 19 69	7 267 563 953	44·0113622	12·4655049	·0005162623
3 75 58 44	7 278 825 672	44·0227214	12·4676497	·0005159959
3 75 97 21	7 290 099 019	44·0340777	12·4697937	·0005157298
3 76 36 00	7 301 384 000	44·0454311	12·4719370	·0005154639
3 76 74 81	7 312 680 621	44·0567815	12·4740796	·0005151984
3 77 13 64	7 323 988 888	44·0681291	12·4762214	·0005149331
3 77 52 49	7 335 308 807	44·0794737	12·4783625	·0005146680
3 77 91 36	7 346 640 384	44·0908154	12·4805029	·0005144033
3 78 30 25	7 357 983 625	44·1021541	12·4826426	·0005141388
3 78 69 16	7 369 338 536	44·1134900	12·4847815	·0005138746
3 79 08 09	7 380 705 123	44·1248229	12·4869197	·0005136107
3 79 47 04	7 392 083 392	44·1361530	12·4890571	·0005133470
3 79 86 01	7 403 473 349	44·1474801	12·4911938	·0005130836
3 80 25 00	7 414 875 000	44·1588043	12·4933298	·0005128205
3 80 64 01	7 426 288 351	44·1701256	12·4954651	·0005125577
3 81 03 04	7 437 713 408	44·1814441	12·4975995	·0005122951
3 81 42 09	7 449 150 177	44·1927596	12·4997333	·0005120328
3 81 81 16	7 460 598 664	44·2040722	12·5018664	·0005117707
3 82 20 25	7 472 058 875	44·2153819	12·5039988	·0005115090
3 82 59 36	7 483 530 816	44·2266888	12·5061304	·0005112474

No.	Square	Cube	Square Root	Cube Root	Reciprocal
1957	3 82 98 49	7 495 014 493	44·2379927	12·5082612	·0005109862
1958	3 83 37 64	7 506 509 912	44·2492938	12·5103914	·0005107252
1959	3 83 76 81	7 518 017 079	44·2605919	12·5125208	·0005104645
1960	3 84 16 00	7 529 536 000	44·2718872	12·5146495	·0005102041
1961	3 84 55 21	7 541 066 681	44·2831797	12·5167775	·0005099439
1962	3 84 94 44	7 552 609 128	44·2944692	12·5189047	·0005096840
1963	3 85 33 69	7 564 163 347	44·3057558	12·5210313	·0005094244
1964	3 85 72 96	7 575 729 344	44·3170396	12·5231571	·0005091650
1965	3 86 12 25	7 587 307 125	44·3283205	12·5252822	·0005089059
1966	3 86 51 56	7 598 896 696	44·3395985	12·5274065	·0005086470
1967	3 86 90 89	7 610 498 063	44·3508737	12·5295302	·0005083884
1968	3 87 30 24	7 622 111 232	44·3621460	12·5316531	·0005081301
1969	3 87 69 61	7 633 736 209	44·3734155	12·5337753	·0005078720
1970	3 88 09 00	7 645 373 000	44·3846820	12·5358968	·0005076142
1971	3 88 48 41	7 657 021 611	44·3959457	12·5380176	·0005073567
1972	3 88 87 84	7 668 682 048	44·4072066	12·5401377	·0005070994
1973	3 89 27 29	7 680 354 317	44·4184646	12·5422570	·0005068424
1974	3 89 66 76	7 692 038 424	44·4297198	12·5443757	·0005065856
1975	3 90 06 25	7 703 734 375	44·4409720	12·5464936	·0005063291
1976	3 90 45 76	7 715 442 176	44·4522215	12·5486107	·0005060729
1977	3 90 85 29	7 727 161 833	44·4634681	12·5507272	·0005058169
1978	3 91 24 84	7 738 893 352	44·4747119	12·5528430	·0005055612
1979	3 91 64 41	7 750 636 739	44·4859528	12·5549580	·0005053057
1980	3 92 04 00	7 762 392 000	44·4971909	12·5570723	·0005050505
1981	3 92 43 61	7 774 159 141	44·5084262	12·5591860	·0005047956
1982	3 92 83 24	7 785 938 168	44·5196586	12·5612989	·0005045409
1983	3 93 22 89	7 797 729 087	44·5308881	12·5634111	·0005042864
1984	3 93 62 56	7 809 531 904	44·5421149	12·5655226	·0005040323
1985	3 94 02 25	7 821 346 625	44·5533388	12·5676334	·0005037783
1986	3 94 41 96	7 833 173 256	44·5645599	12·5697435	·0005035247
1987	3 94 81 69	7 845 011 803	44·5757781	12·5718529	·0005032713
1988	3 95 21 44	7 856 862 272	44·5869936	12·5739615	·0005030181
1989	3 95 61 21	7 868 724 669	44·5982062	12·5760695	·0005027652
1990	3 96 01 00	7 880 599 000	44·6094160	12·5781767	·0005025126
1991	3 96 40 81	7 892 485 271	44·6206230	12·5802832	·0005022602
1992	3 96 80 64	7 904 383 488	44·6318272	12·5823891	·0005020080
1993	3 97 20 49	7 916 293 657	44·6430286	12·5844942	·0005017561
1994	3 97 60 36	7 928 215 784	44·6542271	12·5865987	·0005015045
1995	3 98 00 25	7 940 149 875	44·6654228	12·5887024	·0005012531
1996	3 98 40 16	7 952 095 936	44·6766158	12·5908054	·0005010020
1997	3 98 80 09	7 964 053 973	44·6878059	12·5929078	·0005007511
1998	3 99 20 04	7 976 023 992	44·6989933	12·5950094	·0005005005
1999	3 99 60 01	7 988 005 999	44·7101778	12·5971103	·0005002501
2000	4 00 00 00	8 000 000 000	44·7213596	12·5992105	·0005000000
2001	4 00 40 01	8 012 006 001	44·7325385	12·6013101	·0004997501
2002	4 00 80 04	8 024 024 008	44·7437146	12·6034089	·0004995005
2003	4 01 20 09	8 036 054 027	44·7548880	12·6055070	·0004992511
2004	4 01 60 16	8 048 096 064	44·7660586	12·6076044	·0004990020
2005	4 02 00 25	8 060 150 125	44·7772264	12·6097011	·0004987531

Square	Cube	Square Root	Cube Root	Reciprocal
4 02 40 36	8 072 216 216	44·7883913	12·6117971	·0004985045
4 02 80 49	8 084 294 343	44·7995535	12·6138924	·0004982561
4 03 20 64	8 096 384 512	44·8107130	12·6159870	·0004980080
4 03 60 81	8 108 486 729	44·8218697	12·6180810	·0004977601
4 04 01 00	8 120 601 000	44·8330235	12·6201743	·0004975124
4 04 41 21	8 132 727 331	44·8441746	12·6222669	·0004972650
4 04 81 44	8 144 865 728	44·8553230	12·6243587	·0004970179
4 05 21 69	8 157 016 197	44·8664685	12·6264499	·0004967710
4 05 61 96	8 169 178 744	44·8776113	12·6285404	·0004965243
4 06 02 25	8 181 353 375	44·8887514	12·6306301	·0004962779
4 06 42 56	8 193 540 096	44·8998886	12·6327192	·0004960317
4 06 82 89	8 205 738 913	44·9110231	12·6348076	·0004957858
4 07 23 24	8 217 949 832	44·9221549	12·6368953	·0004955401
4 07 63 61	8 230 172 859	44·9332839	12·6389823	·0004952947
4 08 04 00	8 242 408 000	44·9444101	12·6410687	·0004950495
4 08 44 41	8 254 655 261	44·9555336	12·6431543	·0004948046
4 08 84 84	8 266 914 648	44·9666543	12·6452393	·0004945598
4 09 25 29	8 279 186 167	44·9777723	12·6473235	·0004943154
4 09 65 76	8 291 469 824	44·9888875	12·6494071	·0004940711
4 10 06 25	8 303 765 625	45·0000000	12·6514900	·0004938272
4 10 46 76	8 316 073 576	45·0111097	12·6535722	·0004935834
4 10 87 29	8 328 393 683	45·0222167	12·6556538	·0004933399
4 11 27 84	8 340 725 952	45·0333210	12·6577346	·0004930966
4 11 68 41	8 353 070 389	45·0444225	12·6598148	·0004928536
4 12 09 00	8 365 427 000	45·0555213	12·6618943	·0004926108
4 12 49 61	8 377 795 791	45·0666173	12·6639731	·0004923683
4 12 90 24	8 390 176 768	45·0777107	12·6660512	·0004921260
4 13 30 89	8 402 569 937	45·0888013	12·6681286	·0004918839
4 13 71 56	8 414 975 304	45·0998891	12·6702053	·0004916421
4 14 12 25	8 427 392 875	45·1109743	12·6722814	·0004914005
4 14 52 96	8 439 822 656	45·1220567	12·6743567	·0004911591
4 14 93 69	8 452 264 653	45·1331364	12·6764314	·0004909180
4 15 34 44	8 464 718 872	45·1442134	12·6785054	·0004906771
4 15 75 21	8 477 185 319	45·1552876	12·6805788	·0004904365
4 16 16 00	8 489 664 000	45·1663592	12·6826514	·0004901961
4 16 56 81	8 502 154 921	45·1774280	12·6847234	·0004899559
4 16 97 64	8 514 658 088	45·1884941	12·6867947	·0004897160
4 17 38 49	8 527 173 507	45·1995575	12·6888654	·0004894762
4 17 79 36	8 539 701 184	45·2106182	12·6909354	·0004892368
4 18 20 25	8 552 241 125	45·2216762	12·6930047	·0004889976
4 18 61 16	8 564 793 336	45·2327315	12·6950733	·0004887586
4 19 02 09	8 577 357 823	45·2437841	12·6971412	·0004885198
4 19 43 04	8 589 934 592	45·2548340	12·6992084	·0004882813
4 19 84 01	8 602 523 649	45·2658812	12·7012750	·0004880429
4 20 25 00	8 615 125 000	45·2769257	12·7033409	·0004878049
4 20 66 01	8 627 738 651	45·2879675	12·7054061	·0004875670
4 21 07 04	8 640 364 608	45·2990066	12·7074707	·0004873294
4 21 48 09	8 653 002 877	45·3100430	12·7095346	·0004870921
4 21 89 16	8 665 653 464	45·3210768	12·7115978	·0004868549

No.	Square	Cube	Square Root	Cube Root	Reciprocal
2055	4 22 30 25	8 678 316 375	45·3321078	12·7136603	·0004866180
2056	4 22 71 36	8 690 991 616	45·3431362	12·7157222	·0004863813
2057	4 23 12 49	8 703 679 193	45·3541619	12·7177835	·0004861449
2058	4 23 53 64	8 716 379 112	45·3651849	12·7198441	·0004859086
2059	4 23 94 81	8 729 091 379	45·3762052	12·7219040	·0004856727
2060	4 24 36 00	8 741 816 000	45·3872229	12·7239632	·0004854369
2061	4 24 77 21	8 754 552 981	45·3982378	12·7260218	·0004852014
2062	4 25 18 44	8 767 302 328	45·4092501	12·7280797	·0004849661
2063	4 25 59 69	8 780 064 047	45·4202598	12·7301370	·0004847310
2064	4 26 00 96	8 792 838 144	45·4312668	12·7321935	·0004844961
2065	4 26 42 25	8 805 624 625	45·4422711	12·7342494	·0004842615
2066	4 26 83 56	8 818 423 496	45·4532727	12·7363046	·0004840271
2067	4 27 24 89	8 831 234 763	45·4642717	12·7383592	·0004837929
2068	4 27 66 24	8 844 058 432	45·4752680	12·7404131	·0004835590
2069	4 28 07 61	8 856 894 509	45·4862616	12·7424664	·0004833253
2070	4 28 49 00	8 869 743 000	45·4972526	12·7445189	·0004830918
2071	4 28 90 41	8 882 603 911	45·5082410	12·7465709	·0004828585
2072	4 29 31 84	8 895 477 248	45·5192267	12·7486222	·0004826255
2073	4 29 73 29	8 908 363 017	45·5302097	12·7506728	·0004823927
2074	4 30 14 76	8 921 261 224	45·5411901	12·7527227	·0004821601
2075	4 30 56 25	8 934 171 875	45·5521679	12·7547721	·0004819277
2076	4 30 97 76	8 947 094 976	45·5631430	12·7568207	·0004816956
2077	4 31 39 29	8 960 030 533	45·5741155	12·7588687	·0004814636
2078	4 31 80 84	8 972 978 552	45·5850853	12·7609160	·0004812320
2079	4 32 22 41	8 985 939 039	45·5960525	12·7629627	·0004810005
2080	4 32 64 00	8 998 912 000	45·6070170	12·7650087	·0004807692
2081	4 33 05 61	9 011 897 441	45·6179789	12·7670540	·0004805382
2082	4 33 47 24	9 024 895 368	45·6289382	12·7690987	·0004803074
2083	4 33 88 89	9 037 905 787	45·6398948	12·7711427	·0004800768
2084	4 34 30 56	9 050 928 704	45·6508488	12·7731861	·0004798464
2085	4 34 72 25	9 063 964 125	45·6618002	12·7752288	·0004796163
2086	4 35 13 96	9 077 012 056	45·6727490	12·7772709	·0004793864
2087	4 35 55 69	9 090 072 503	45·6836951	12·7793123	·0004791567
2088	4 35 97 44	9 103 145 472	45·6946386	12·7813531	·0004789272
2089	4 36 39 21	9 116 230 969	45·7055795	12·7833932	·0004786979
2090	4 36 81 00	9 129 329 000	45·7165178	12·7854326	·0004784689
2091	4 37 22 81	9 142 439 571	45·7274534	12·7874714	·0004782401
2092	4 37 64 64	9 155 562 688	45·7383865	12·7895096	·0004780115
2093	4 38 06 49	9 168 698 357	45·7493169	12·7915471	·0004777831
2094	4 38 48 36	9 181 846 584	45·7602447	12·7935840	·0004775549
2095	4 38 90 25	9 195 007 375	45·7711699	12·7956202	·0004773270
2096	4 39 32 16	9 208 180 736	45·7820926	12·7976558	·0004770992
2097	4 39 74 09	9 221 366 673	45·7930126	12·7996907	·0004768717
2098	4 40 16 04	9 234 565 192	45·8039299	12·8017250	·0004766444
2099	4 40 58 01	9 247 776 299	45·8148447	12·8037586	·0004764173
2100	4 41 00 00	9 261 000 000	45·8257569	12·8057916	·0004761905
2101	4 41 42 01	9 274 236 301	45·8366665	12·8078239	·0004759638
2102	4 41 84 04	9 287 485 208	45·8475735	12·8098556	·0004757374
2103	4 42 26 09	9 300 746 727	45·8584779	12·8118866	·0004755112

No.	Square	Cube	Square Root	Cube Root	Reciprocal
2104	4 42 68 16	9 314 020 864	45·8693798	12·8139170	·0004752852
2105	4 43 10 25	9 327 307 625	45·8802790	12·8159468	·0004750594
2106	4 43 52 36	9 340 607 016	45·8911756	12·8179759	·0004748338
2107	4 43 94 49	9 353 919 043	45·9020696	12·8200044	·0004746084
2108	4 44 36 64	9 367 243 712	45·9129611	12·8220323	·0004743833
2109	4 44 78 81	9 380 581 029	45·9238500	12·8240595	·0004741584
2110	4 45 21 00	9 393 931 000	45·9347363	12·8260861	·0004739336
2111	4 45 63 21	9 407 293 631	45·9456200	12·8281120	·0004737091
2112	4 46 05 44	9 420 668 928	45·9565012	12·8301373	·0004734848
2113	4 46 47 69	9 434 056 897	45·9673798	12·8321620	·0004732608
2114	4 46 89 96	9 447 457 544	45·9782557	12·8341860	·0004730369
2115	4 47 32 25	9 460 870 875	45·9891291	12·8362094	·0004728132
2116	4 47 74 56	9 474 296 896	46·0000000	12·8382321	·0004725898
2117	4 48 16 89	9 487 735 613	46·0108683	12·8402542	·0004723666
2118	4 48 59 24	9 501 187 032	46·0217340	12·8422756	·0004721435
2119	4 49 01 61	9 514 651 159	46·0325971	12·8442964	·0004719207
2120	4 49 44 00	9 528 128 000	46·0434577	12·8463166	·0004716981
2121	4 49 86 41	9 541 617 561	46·0543158	12·8483361	·0004714757
2122	4 50 28 84	9 555 119 848	46·0651712	12·8503551	·0004712535
2123	4 50 71 29	9 568 634 867	46·0760241	12·8523733	·0004710316
2124	4 51 13 76	9 582 162 624	46·0868745	12·8543910	·0004708098
2125	4 51 56 25	9 595 703 125	46·0977223	12·8564080	·0004705882
2126	4 51 98 76	9 609 256 376	46·1085675	12·8584243	·0004703669
2127	4 52 41 29	9 622 822 383	46·1194102	12·8604401	·0004701457
2128	4 52 83 84	9 636 401 152	46·1302504	12·8624552	·0004699248
2129	4 53 26 41	9 649 992 689	46·1410880	12·8644697	·0004697041
2130	4 53 69 00	9 663 597 000	46·1519230	12·8664835	·0004694836
2131	4 54 11 61	9 677 214 091	46·1627555	12·8684967	·0004692633
2132	4 54 54 24	9 690 843 968	46·1735855	12·8705093	·0004690432
2133	4 54 96 89	9 704 486 637	46·1844130	12·8725213	·0004688233
2134	4 55 39 56	9 718 142 104	46·1952378	12·8745326	·0004686036
2135	4 55 82 25	9 731 810 375	46·2060602	12·8765433	·0004683841
2136	4 56 24 96	9 745 491 456	46·2168800	12·8785534	·0004681648
2137	4 56 67 69	9 759 185 353	46·2276973	12·8805628	·0004679457
2138	4 57 10 44	9 772 892 072	46·2385121	12·8825717	·0004677268
2139	4 57 53 21	9 786 611 619	46·2493243	12·8845799	·0004675082
2140	4 57 96 00	9 800 344 000	46·2601340	12·8865874	·0004672897
2141	4 58 38 81	9 814 089 221	46·2709412	12·8885944	·0004670715
2142	4 58 81 64	9 827 847 288	46·2817459	12·8906007	·0004668534
2143	4 59 24 49	9 841 618 207	46·2925480	12·8926064	·0004666356
2144	4 59 67 36	9 855 401 984	46·3033476	12·8946115	·0004664179
2145	4 60 10 25	9 869 198 625	46·3141447	12·8966159	·0004662005
2146	4 60 53 16	9 883 008 136	46·3249393	12·8986197	·0004659832
2147	4 60 96 09	9 896 830 523	46·3357314	12·9006229	·0004657662
2148	4 61 39 04	9 910 665 792	46·3465209	12·9026255	·0004655493
2149	4 61 82 01	9 924 513 949	46·3573079	12·9046275	·0004653327
2150	4 62 25 00	9 938 375 000	46·3680924	12·9066288	·0004651163
2151	4 62 68 01	9 952 248 951	46·3788745	12·9086295	·0004649000
2152	4 63 11 04	9 966 135 808	46·3896540	12·9106296	·0004646840

No.	Square	Cube	Square Root	Cube Root	Reciprocal
2153	4 63 54 09	9 980 035 577	46·4004310	12·9126291	·0004644682
2154	4 63 97 16	9 993 948 264	46·4112055	12·9146279	·0004642526
2155	4 64 40 25	10 007 873 875	46·4219775	12·9166262	·0004640371
2156	4 64 83 36	10 021 812 416	46·4327471	12·9186238	·0004638219
2157	4 65 26 49	10 035 763 893	46·4435141	12·9206208	·0004636069
2158	4 65 69 64	10 049 728 312	46·4542786	12·9226172	·0004633920
2159	4 66 12 81	10 063 705 679	46·4650406	12·9246129	·0004631774
2160	4 66 56 00	10 077 696 000	46·4758002	12·9266081	·0004629630
2161	4 66 99 21	10 091 699 281	46·4865572	12·9286027	·0004627487
2162	4 67 42 44	10 105 715 528	46·4973118	12·9305966	·0004625347
2163	4 67 85 69	10 119 744 747	46·5080638	12·9325899	·0004623209
2164	4 68 28 96	10 133 786 944	46·5188134	12·9345827	·0004621072
2165	4 68 72 25	10 147 842 125	46·5295605	12·9365747	·0004618938
2166	4 69 15 56	10 161 910 296	46·5403051	12·9385662	·0004616805
2167	4 69 58 89	10 175 991 463	46·5510472	12·9405570	·0004614675
2168	4 70 02 24	10 190 085 632	46·5617869	12·9425472	·0004612546
2169	4 70 45 61	10 204 192 809	46·5725241	12·9445369	·0004610420
2170	4 70 89 00	10 218 313 000	46·5832588	12·9465259	·0004608295
2171	4 71 32 41	10 232 446 211	46·5939910	12·9485143	·0004606172
2172	4 71 75 84	10 246 592 448	46·6047208	12·9505021	·0004604052
2173	4 72 19 29	10 260 751 717	46·6154481	12·9524893	·0004601933
2174	4 72 62 76	10 274 924 024	46·6261729	12·9544759	·0004599816
2175	4 73 06 25	10 289 109 375	46·6368953	12·9564618	·0004597701
2176	4 73 49 76	10 303 307 776	46·6476152	12·9584472	·0004595588
2177	4 73 93 29	10 317 519 233	46·6583326	12·9604319	·0004593477
2178	4 74 36 84	10 331 743 752	46·6690476	12·9624161	·0004591368
2179	4 74 80 41	10 345 981 339	46·6797601	12·9643996	·0004589261
2180	4 75 24 00	10 360 232 000	46·6904701	12·9663826	·0004587156
2181	4 75 67 61	10 374 495 741	46·7011777	12·9683649	·0004585053
2182	4 76 11 24	10 388 772 568	46·7118829	12·9703466	·0004582951
2183	4 76 54 89	10 403 062 487	46·7225855	12·9723277	·0004580852
2184	4 76 98 56	10 417 365 504	46·7332858	12·9743082	·0004578755
2185	4 77 42 25	10 431 681 625	46·7439836	12·9762881	·0004576659
2186	4 77 85 96	10 446 010 856	46·7546789	12·9782674	·0004574565
2187	4 78 29 69	10 460 353 203	46·7653718	12·9802461	·0004572474
2188	4 78 73 44	10 474 708 672	46·7760623	12·9822242	·0004570384
2189	4 79 17 21	10 489 077 269	46·7867503	12·9842017	·0004568296
2190	4 79 61 00	10 503 459 000	46·7974358	12·9861786	·0004566210
2191	4 80 04 81	10 517 853 871	46·8081189	12·9881549	·0004564126
2192	4 80 48 64	10 532 261 888	46·8187996	12·9901306	·0004562044
2193	4 80 92 49	10 546 683 057	46·8294779	12·9921057	·0004559964
2194	4 81 36 36	10 561 117 384	46·8401537	12·9940802	·0004557885
2195	4 81 80 25	10 575 564 875	46·8508271	12·9960540	·0004555809
2196	4 82 24 16	10 590 025 536	46·8614981	12·9980273	·0004553734
2197	4 82 68 09	10 604 499 373	46·8721666	13·0000000	·0004551661
2198	4 83 12 04	10 618 986 392	46·8828327	13·0019721	·0004549591
2199	4 83 56 01	10 633 486 599	46·8934963	13·0039436	·0004547522
2200	4 84 00 00	10 648 000 000	46·9041576	13·0059145	·0004545455
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11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969					3	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	7	10	12	16	19	22	25	29
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	28
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	5	8	11	14	16	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	15	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	19	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	16	19	21
						2672	2695	2718	2742	2765	2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16

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27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
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31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
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36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
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42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
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45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
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47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
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50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

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60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
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47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12

·	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	8	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

Exponential and Hyperbolic Functions.

.	e^x.	e^{-x}.	Cosh x.	Sinh x.	x.	e^x.	e^{-x}.	Cosh x.	Sinh x.
0	1·0000	1·0000	1·0000	·0000	·40	1·4918	·6703	1·0811	·4108
1	1·0100	·9900	1·0000	·0100	·41	1·5068	·6636	1·0852	·4216
2	1·0202	·9802	1·0002	·0200	·42	1·5220	·6570	1·0895	·4325
3	1·0304	·9704	1·0004	·0300	·43	1·5373	·6505	1·0939	·4434
4	1·0408	·9608	1·0008	·0400	·44	1·5527	·6440	1·0984	·4543
5	1·0513	·9512	1·0012	·0500	·45	1·5683	·6376	1·1030	·4653
6	1·0618	·9418	1·0018	·0600	·46	1·5841	·6313	1·1077	·4764
7	1·0725	·9324	1·0024	·0701	·47	1·6000	·6250	1·1125	·4875
8	1·0833	·9231	1·0032	·0801	·48	1·6161	·6188	1·1174	·4986
9	1·0942	·9139	1·0040	·0901	·49	1·6323	·6126	1·1225	·5098
.0	1·1052	·9048	1·0050	·1002	·50	1·6487	·6065	1·1276	·5211
.1	1·1163	·8958	1·0061	·1102	·51	1·6653	·6005	1·1329	·5324
.2	1·1275	·8869	1·0072	·1203	·52	1·6820	·5945	1·1383	·5438
.3	1·1388	·8781	1·0085	·1304	·53	1·6989	·5886	1·1438	·5552
.4	1·1503	·8694	1·0098	·1405	·54	1·7160	·5828	1·1494	·5666
.5	1·1618	·8607	1·0113	·1506	·55	1·7332	·5770	1·1551	·5782
.6	1·1735	·8521	1·0128	·1607	·56	1·7507	·5712	1·1609	·5897
.7	1·1853	·8437	1·0145	·1708	·57	1·7683	·5655	1·1669	·6014
.8	1·1972	·8353	1·0162	·1810	·58	1·7860	·5599	1·1730	·6131
.9	1·2092	·8270	1·0181	·1912	·59	1·8040	·5543	1·1792	·6248
0	1·2214	·8187	1·0201	·2013	·60	1·8221	·5488	1·1855	·6366
1	1·2337	·8106	1·0221	·2116	·61	1·8404	·5434	1·1919	·6485
2	1·2461	·8025	1·0243	·2218	·62	1·8589	·5379	1·1984	·6605
3	1·2586	·7945	1·0266	·2320	·63	1·8776	·5326	1·2051	·6725
4	1·2712	·7866	1·0289	·2423	·64	1·8965	·5273	1·2119	·6846
5	1·2840	·7788	1·0314	·2526	·65	1·9155	·5220	1·2188	·6968
6	1·2969	·7710	1·0340	·2629	·66	1·9348	·5168	1·2258	·7090
7	1·3100	·7634	1·0367	·2733	·67	1·9542	·5117	1·2330	·7213
8	1·3231	·7558	1·0395	·2837	·68	1·9739	·5066	1·2402	·7336
9	1·3364	·7483	1·0424	·2941	·69	1·9937	·5016	1·2476	·7461
0	1·3499	·7408	1·0453	·3045	·70	2·0138	·4966	1·2552	·7586
1	1·3634	·7334	1·0484	·3150	·71	2·0340	·4916	1·2628	·7712
2	1·3771	·7262	1·0516	·3255	·72	2·0544	·4868	1·2706	·7838
3	1·3910	·7189	1·0550	·3360	·73	2·0751	·4819	1·2785	·7966
4	1·4050	·7118	1·0584	·3466	·74	2·0959	·4771	1·2865	·8094
5	1·4190	·7047	1·0619	·3572	·75	2·1170	·4724	1·2947	·8223
6	1·4333	·6977	1·0655	·3678	·76	2·1383	·4677	1·3030	·8353
7	1·4477	·6907	1·0692	·3785	·77	2·1598	·4630	1·3114	·8484
8	1·4623	·6839	1·0731	·3892	·78	2·1815	·4584	1·3199	·8615
9	1·4770	·6771	1·0770	·4000	·79	2·2034	·4538	1·3286	·8748

Exponential and Hyperbolic Functions—*Continued.*

x.	e^{x}.	e^{-x}.	Cosh x.	Sinh x.	x.	e^{x}.	e^{-x}.	Cosh x.	Sinh x.
·80	2·2255	·4493	1·3374	·8881	1·20	3·3201	·3012	1·8107	1·5095
·81	2·2479	·4449	1·3464	·9015	1·21	3·3535	·2982	1·8258	1·5276
·82	2·2705	·4404	1·3555	·9150	1·22	3·3872	·2952	1·8412	1·5460
·83	2·2933	·4360	1·3647	·9286	1·23	3·4212	·2923	1·8568	1·5645
·84	2·3161	·4317	1·3740	·9423	1·24	3·4556	·2894	1·8725	1·5831
·85	2·3396	·4274	1·3835	·9561	1·25	3·4903	·2865	1·8884	1·6019
·86	2·3632	·4232	1·3932	·9700	1·26	3·5251	·2836	1·9045	1·6209
·87	2·3869	·4190	1·4029	·9840	1·27	3·5608	·2808	1·9208	1·6400
·88	2·4109	·4148	1·4128	·9981	1·28	3·5966	·2780	1·9373	1·6593
·89	2·4351	·4107	1·4229	1·0122	1·29	3·6328	·2753	1·9540	1·6788
·90	2·4596	·4066	1·4331	1·0265	1·30	3·6693	·2725	1·9709	1·6984
·91	2·4843	·4025	1·4434	1·0409	1·31	3·7062	·2698	1·9880	1·7182
·92	2·5093	·3985	1·4539	1·0554	1·32	3·7434	·2671	2·0053	1·7381
·93	2·5345	·3946	1·4645	1·0700	1·33	3·7810	·2645	2·0228	1·7583
·94	2·5600	·3906	1·4755	1·0847	1·34	3·8190	·2618	2·0404	1·7786
·95	2·5857	·3867	1·4862	1·0995	1·35	3·8574	·2592	2·0583	1·7991
·96	2·6117	·3829	1·4973	1·1144	1·36	3·8932	·2567	2·0764	1·8198
·97	2·6379	·3791	1·5085	1·1294	1·37	3·9354	·2541	2·0947	1·8406
·98	2·6645	·3753	1·5199	1·1446	1·38	3·9749	·2516	2·1132	1·8617
·99	2·6912	·3716	1·5314	1·1598	1·39	4·0148	·2491	2·1320	1·8829
1·00	2·7183	·3679	1·5431	1·1752	1·40	4·0552	·2466	2·1509	1·9043
1·01	2·7456	·3642	1·5549	1·1907	1·41	4·0960	·2441	2·1700	1·9259
1·02	2·7732	·3606	1·5669	1·2063	1·42	4·1371	·2417	2·1894	1·9477
1·03	2·8011	·3570	1·5790	1·2220	1·43	4·1787	·2393	2·2090	1·9697
1·04	2·8292	·3534	1·5913	1·2379	1·44	4·2207	·2369	2·2288	1·9919
1·05	2·8576	·3499	1·6038	1·2539	1·45	4·2631	·2346	2·2488	2·0143
1·06	2·8864	·3465	1·6164	1·2700	1·46	4·3060	·2322	2·2691	2·0369
1·07	2·9151	·3430	1·6292	1·2862	1·47	4·3492	·2299	2·2896	2·0596
1·08	2·9447	·3396	1·6421	1·3025	1·48	4·3930	·2276	2·3103	2·0826
1·09	2·9743	·3362	1·6552	1·3190	1·49	4·4371	·2254	2·3312	2·1059
1·10	3·0042	·3329	1·6685	1·3356	1·50	4·4817	·2231	2·3524	2·1293
1·11	3·0314	·3296	1·6820	1·3524	1·51	4·5267	·2209	2·3738	2·1529
1·12	3·0648	·3265	1·6958	1·3695	1·52	4·5722	·2187	2·3955	2·1768
1·13	3·0957	·3230	1·7093	1·3863	1·53	4·6182	·2165	2·4174	2·2008
1·14	3·1268	·3198	1·7233	1·4035	1·54	4·6646	·2144	2·4395	2·2251
1·15	3·1582	·3166	1·7374	1·4208	1·55	4·7115	·2122	2·4619	2·2496
1·16	3·1899	·3135	1·7517	1·4382	1·56	4·7588	·2101	2·4845	2·2743
1·17	3·2220	·3104	1·7662	1·4559	1·57	4·8066	·2080	2·5074	2·2993
1·18	3·2514	·3073	1·7808	1·4736	1·58	4·8550	·2060	2·5305	2·3245
1·19	3·2871	·3042	1·7956	1·4914	1·59	4·9038	·2039	2·5538	2·3499

Exponential and Hyperbolic Functions—*Continued.*

x.	e^{x}.	e^{-x}.	Cosh x	Sinh x.	x.	e^{x}.	e^{-x}.	Cosh x.	Sinh x.
·60	4·9530	·2019	2·5775	2·3756	2·00	7·3891	·1353	3·7622	3·6269
·61	5·0028	·1999	2·6014	2·4015	2·1	8·1662	·1225	4·1443	4·0219
·62	5·0531	·1979	2·6255	2·4276	2·2	9·0250	·1108	4·5679	4·4571
·63	5·1039	·1959	2·6499	2·4540	2·3	9·9742	·1003	5·0372	4·9370
·64	5·1552	·1940	2·6746	2·4806	2·4	11·0232	·0907	5·5570	5·4662
·65	5·2070	·1920	2·6995	2·5075	2·5	12·1825	·0821	6·1323	6·0502
·66	5·2593	·1901	2·7247	2·5346	2·6	13·4637	·0743	6·7690	6·6947
·67	5·3122	·1882	2·7502	2·5620	2·7	14·8797	·0672	7·4735	7·4063
·68	5·3656	·1864	2·7760	2·5896	2·8	16·4446	·0608	8·2527	8·1919
·69	5·4195	·1845	2·8020	2·6175	2·9	18·1741	·0550	9·1146	9·0596
·70	5·4740	·1827	2·8283	2·6456	3·0	20·0855	·0498	10·0677	10·0179
·71	5·5290	·1809	2·8549	2·6740	3·1	22·1980	·0450	11·1215	11·0765
·72	5·5845	·1791	2·8818	2·7027	3·2	24·5325	·0408	12·2866	12·2459
·73	5·6406	·1773	2·9090	2·7317	3·3	27·1126	·0369	13·5747	13·5379
·74	5·6973	·1755	2·9364	2·7609	3·4	29·9641	·0334	14·9987	14·9654
·75	5·7546	·1738	2·9642	2·7904	3·5	33·1155	·0302	16·5728	16·5426
·76	5·8124	·1720	2·9922	2·8202	3·6	36·5982	·0273	18·3128	18·2855
·77	5·8708	·1703	3·0206	2·8503	3·7	40·4473	·0247	20·2360	20·2113
·78	5·9299	·1686	3·0492	2·8806	3·8	44·7012	·0224	22·3618	22·3394
·79	5·9894	·1670	3·0782	2·9112	3·9	49·4024	·0202	24·7113	24·6911
·80	6·0496	·1653	3·1075	2·9422	4·0	54·5982	·0183	27·3082	27·2899
·81	6·1104	·1635	3·1370	2·9734	4·1	60·3403	·0166	30·1784	30·1619
·82	6·1719	·1620	3·1669	3·0049	4·2	66·6863	·0150	33·3507	33·3357
·83	6·2339	·1604	3·1972	3·0367	4·3	73·6998	·0136	36·8567	36·8431
·84	6·2965	·1588	3·2277	3·0689	4·4	81·4509	·0123	40·7316	40·7193
·85	6·3598	·1572	3·2585	3·1013	4·5	90·0171	·0111	45·0141	45·0030
·86	6·4237	·1557	3·2897	3·1340	4·6	99·4843	·0100	49·7472	49·7371
·87	6·4883	·1541	3·3212	3·1671	4·7	109·947	·0091	54·9781	54·9690
·88	6·5535	·1526	3·3530	3·2005	4·8	121·510	·0082	60·7593	60·7511
·89	6·6194	·1511	3·3852	3·2342	4·9	134·290	·0074	67·1486	67·1412
·90	6·6859	·1496	3·4177	3·2682	5·0	148·413	·0067	74·2099	74·2032
·91	6·7531	·1481	3·4506	3·3025	5·1	164·022	·0061	82·0140	82·0079
·92	6·8210	·1466	3·4838	3·3372	5·2	181·272	·0055	90·6388	90·6333
·93	6·8895	·1452	3·5173	3·3722	5·3	200·337	·0050	100·171	100·167
·94	6·9588	·1437	3·5512	3·4075	5·4	221·406	·0045	110·705	110·701
·95	7·0287	·1423	3·5855	3·4432	5·5	244·692	·0041	122·348	122·344
·96	7·0993	·1409	3·6201	3·4792	5·6	270·426	·0037	135·215	135·211
·97	7·1707	·1395	3·6551	3·5156	5·7	298·867	·0034	149·435	149·432
·98	7·2427	·1381	3·6904	3·5523	5·8	330·300	·0030	165·151	165·148
·99	7·3155	·1367	3·7261	3·5894	5·9	365·037	·0027	182·520	182·517
					6·0	403·429	·0025	201·716	201·713

Table of Hyperbolic Logarithms.

To find the hyperbolic logarithm of a number multiply the common logarithm of the number by the figures 2·302585052994, and the product is the hyperbolic logarithm of that number.

Example.—The common logarithm of 3·75 is ·5740313; the hyperbolic logarithm is then found by multiplying 2·302585 by ·5740313 = 1·3217559, the hyperbolic logarithm.

No.	Logarithm	No.	Logarithm	No.	Logarithm	No.	Logarithm
1·01	·0099503	1·35	·3001046	1·69	·5247284	2·03	·7080357
1·02	·0198026	1·36	·3074847	1·70	·5306282	2·04	·7129497
1·03	·0295588	1·37	·3148108	1·71	·5364933	2·05	·7178399
1·04	·0392207	1·38	·3220833	1·72	·5423241	2·06	·7227058
1·05	·0487902	1·39	·3293037	1·73	·5481212	2·07	·7275485
1·06	·0582690	1·40	·3364721	1·74	·5538850	2·08	·7323678
1·07	·0676586	1·41	·3435895	1·75	·5596156	2·09	·7371640
1·08	·0769610	1·42	·3506568	1·76	·5653138	2·10	·7419373
1·09	·0861777	1·43	·3576744	1·77	·5709795	2·11	·7466880
1·10	·0953102	1·44	·3646431	1·78	·5766133	2·12	·7514160
1·11	·1043600	1·45	·3715635	1·79	·5822156	2·13	·7561219
1·12	·1133285	1·46	·3784365	1·80	·5877866	2·14	·7608058
1·13	·1222174	1·47	·3852623	1·81	·5933268	2·15	·7654680
1·14	·1310284	1·48	·3920420	1·82	·5988365	2·16	·7701082
1·15	·1397614	1·49	·3987762	1·83	·6043159	2·17	·7747271
1·16	·1484199	1·50	·4054652	1·84	·6097653	2·18	·7793248
1·17	·1570038	1·51	·4121094	1·85	·6151855	2·19	·7839014
1·18	·1655144	1·52	·4187103	1·86	·6205763	2·20	·7884573
1·19	·1739534	1·53	·4252675	1·87	·6259384	2·21	·7929925
1·20	·1823215	1·54	·4317823	1·88	·6312717	2·22	·7975071
1·21	·1906204	1·55	·4382550	1·89	·6365768	2·23	·8020015
1·22	·1988507	1·56	·4446858	1·90	·6418538	2·24	·8064758
1·23	·2070140	1·57	·4510756	1·91	·6471033	2·25	·8109303
1·24	·2151113	1·58	·4574247	1·92	·6523251	2·26	·8153647
1·25	·2231435	1·59	·4637339	1·93	·6575200	2·27	·8197798
1·26	·2311161	1·60	·4700036	1·94	·6626879	2·28	·8241754
1·27	·2390167	1·61	·4762341	1·95	·6678294	2·29	·8285518
1·28	·2468601	1·62	·4824260	1·96	·6729445	2·30	·8329089
1·29	·2546422	1·63	·4885801	1·97	·6780335	2·31	·8372474
1·30	·2623643	1·64	·4946959	1·98	·6830968	2·32	·8415671
1·31	·2700271	1·65	·5007752	1·99	·6881346	2·33	·8458682
1·32	·2776316	1·66	·5068176	2·00	·6931472	2·34	·8501509
1·33	·2851787	1·67	·5128237	2·01	·6981347	2·35	·8544154
1·34	·2926696	1·68	·5187938	2·02	·7030974	2·36	·8586616

No.	Logarithm	No.	Logarithm	No.	Logarithm	No.	Logarithm
·37	·8628899	2·85	1·0473189	3·33	1·2029722	3·81	1·3376291
·38	·8671004	2·86	1·0508215	3·34	1·2059707	3·82	1·3402504
·39	·8712933	2·87	1·0543120	3·35	1·2089603	3·83	1·3428648
·40	·8754686	2·88	1·0577902	3·36	1·2119409	3·84	1·3454723
·41	·8796266	2·89	1·0612564	3·37	1·2149127	3·85	1·3480731
·42	·8837675	2·90	1·0647107	3·38	1·2178757	3·86	1·3506671
·43	·8878912	2·91	1·0681529	3·39	1·2208299	3·87	1·3532544
·44	·8919980	2·92	1·0715836	3·40	1·2237754	3·88	1·3558351
·45	·8960879	2·93	1·0750024	3·41	1·2267122	3·89	1·3584091
·46	·9001613	2·94	1·0784095	3·42	1·2296405	3·90	1·3609765
·47	·9042181	2·95	1·0818051	3·43	1·2325605	3·91	1·3635373
·48	·9082585	2·96	1·0851892	3·44	1·2354714	3·92	1·3660916
·49	·9122826	2·97	1·0885619	3·45	1·2383742	3·93	1·3686395
·50	·9162907	2·98	1·0919233	3·46	1·2412685	3·94	1·3711807
·51	·9202825	2·99	1·0952733	3·47	1·2441545	3·95	1·3737156
·52	·9242589	3·00	1·0986124	3·48	1·2470322	3·96	1·3762440
·53	·9282193	3·01	1·1019400	3·49	1·2499017	3·97	1·3787661
·54	·9321640	3·02	1·1052568	3·50	1·2527629	3·98	1·3812818
·55	·9360934	3·03	1·1085626	3·51	1·2556160	3·99	1·3837911
·56	·9400072	3·04	1·1118575	3·52	1·2584609	4·00	1·3862943
·57	·9439058	3·05	1·1151415	3·53	1·2612978	4·01	1·3887912
·58	·9477893	3·06	1·1184147	3·54	1·2641266	4·02	1·3912818
·59	·9516578	3·07	1·1216775	3·55	1·2669475	4·03	1·3937763
·60	·9555112	3·08	1·1249295	3·56	1·2697605	4·04	1·3962446
·61	·9593502	3·09	1·1281710	3·57	1·2725655	4·05	1·3987168
·62	·9631743	3·10	1·1314021	3·58	1·2753627	4·06	1·4011829
·63	·9669838	3·11	1·1346227	3·59	1·2781521	4·07	1·4036429
·64	·9707789	3·12	1·1378330	3·60	1·2809338	4·08	1·4060969
·65	·9745596	3·13	1·1410330	3·61	1·2837077	4·09	1·4085449
·66	·9783259	3·14	1·1442227	3·62	1·2864740	4·10	1·4109869
·67	·9820784	3·15	1·1474024	3·63	1·2892326	4·11	1·4134230
·68	·9858167	3·16	1·1505718	3·64	1·2919836	4·12	1·4158531
·69	·9895411	3·17	1·1537315	3·65	1·2947271	4·13	1·4182774
·70	·9932518	3·18	1·1568811	3·66	1·2974631	4·14	1·4206957
·71	·9969486	3·19	1·1600209	3·67	1·3001916	4·15	1·4231083
·72	1·0006318	3·20	1·1631508	3·68	1·3029127	4·16	1·4255150
·73	1·0043015	3·21	1·1662708	3·69	1·3056264	4·17	1·4279161
·74	1·0079579	3·22	1·1693813	3·70	1·3083328	4·18	1·4303112
·75	1·0116009	3·23	1·1724821	3·71	1·3110318	4·19	1·4327007
.76	1·0152306	3·24	1·1755733	3·72	1·3137236	4·20	1·4350844
.77	1·0188473	3·25	1·1786549	3·73	1·3164082	4·21	1·4374626
.78	1·0224509	3·26	1·1817271	3·74	1·3190856	4·22	1·4398351
.79	1·0260415	3·27	1·1847899	3·75	1·3217559	4·23	1·4422020
·80	1·0296193	3·28	1·1878434	3·76	1·3244189	4·24	1·4445632
·81	1·0331843	3·29	1·1908875	3·77	1·3270749	4·25	1·4469189
.82	1·0367368	3·30	1·1939224	3·78	1·3297240	4·26	1·4492691
.83	1·0402766	3·31	1·1969481	3·79	1·3323660	4·27	1·4516138
.84	1·0438040	3·32	1·1999647	3·80	1·3350010	4·28	1·4539530

No.	Logarithm	No.	Logarithm	No.	Logarithm	No.	Logarithm
4·29	1·4562867	4·77	1·5623462	5·25	1·6582280	5·73	1·7457155
4·30	1·4586149	4·78	1·5644405	5·26	1·6601310	5·74	1·7474591
4·31	1·4609379	4·79	1·5665304	5·27	1·6620303	5·75	1·7491998
4·32	1·4632553	4·80	1·5686159	5·28	1·6639260	5·76	1·7509374
4·33	1·4655675	4·81	1·5706971	5·29	1·6658182	5·77	1·7526720
4·34	1·4678743	4·82	1·5727739	5·30	1·6677068	5·78	1·7544036
4·35	1·4701758	4·83	1·5748464	5·31	1·6695918	5·79	1·7561323
4·36	1·4724720	4·84	1·5769147	5·32	1·6714733	5·80	1·7578579
4·37	1·4747630	4·85	1·5789787	5·33	1·6733512	5·81	1·7595805
4·38	1·4770487	4·86	1·5810384	5·34	1·6752256	5·82	1·7613002
4·39	1·4793292	4·87	1·5830939	5·35	1·6770965	5·83	1·7630170
4·40	1·4816045	4·88	1·5851452	5·36	1·6789639	5·84	1·7647308
4·41	1·4838746	4·89	1·5871923	5·37	1·6808278	5·85	1·7664416
4·42	1·4861396	4·90	1·5892352	5·38	1·6826882	5·86	1·7681496
4·43	1·4883994	4·91	1·5912739	5·39	1·6845453	5·87	1·7698546
4·44	1·4906543	4·92	1·5933085	5·40	1·6863989	5·88	1·7715567
4·45	1·4929040	4·93	1·5953389	5·41	1·6882491	5·89	1·7732559
4·46	1·4951487	4·94	1·5973653	5·42	1·6900958	5·90	1·7749523
4·47	1·4973883	4·95	1·5993875	5·43	1·6919391	5·91	1·7766458
4·48	1·4996230	4·96	1·6014057	5·44	1·6937790	5·92	1·7783364
4·49	1·5018527	4·97	1·6034198	5·45	1·6956155	5·93	1·7800242
4·50	1·5040773	4·98	1·6054298	5·46	1·6974487	5·94	1·7817091
4·51	1·5062971	4·99	1·6074358	5·47	1·6992786	5·95	1·7833912
4·52	1·5085119	5·00	1·6094377	5·48	1·7011051	5·96	1·7850704
4·53	1·5107219	5·01	1·6114359	5·49	1·7029282	5·97	1·7867469
4·54	1·5129269	5·02	1·6134300	5·50	1·7047481	5·98	1·7884205
4·55	1·5151272	5·03	1·6154200	5·51	1·7065646	5·99	1·7900914
4·56	1·5173226	5·04	1·6174060	5·52	1·7083778	6·00	1·7917595
4·57	1·5195132	5·05	1·6193882	5·53	1·7101878	6·01	1·7934247
4·58	1·5216990	5·06	1·6213664	5·54	1·7119944	6·02	1·7950872
4·59	1·5238800	5·07	1·6233408	5·55	1·7137979	6·03	1·7967470
4·60	1·5260563	5·08	1·6253112	5·56	1·7155981	6·04	1·7984040
4·61	1·5282278	5·09	1·6272778	5·57	1·7173950	6·05	1·8000582
4·62	1·5303947	5·10	1·6292405	5·58	1·7191887	6·06	1·8017098
4·63	1·5325568	5·11	1·6311994	5·59	1·7209792	6·07	1·8033586
4·64	1·5347143	5·12	1·6331544	5·60	1·7227660	6·08	1·8050047
4·65	1·5368672	5·13	1·6351057	5·61	1·7245507	6·09	1·8066481
4·66	1·5390154	5·14	1·6370530	5·62	1·7263316	6·10	1·8082887
4·67	1·5411590	5·15	1·6389967	5·63	1·7281094	6·11	1·8099267
4·68	1·5432981	5·16	1·6409365	5·64	1·7298840	6·12	1·8115621
4·69	1·5454325	5·17	1·6428726	5·65	1·7316555	6·13	1·8131947
4·70	1·5475625	5·18	1·6448050	5·66	1·7334238	6·14	1·8148247
4·71	1·5496879	5·19	1·6467336	5·67	1·7351891	6·15	1·8164520
4·72	1·5518087	5·20	1·6486586	5·68	1·7369512	6·16	1·8180767
4·73	1·5539252	5·21	1·6505798	5·69	1·7387102	6·17	1·8196988
4·74	1·5560371	5·22	1·6524974	5·70	1·7404661	6·18	1·8213182
4·75	1·5581446	5·23	1·6544112	5·71	1·7422189	6·19	1·8229351
4·76	1·5602476	5·24	1·6563214	5·72	1·7439687	6·20	1·8245493

No.	Logarithm	No.	Logarithm	No.	Logarithm	No.	Logarithm
6·21	1·8261608	6·69	1·9006138	7·17	1·9699056	7·65	2·0347056
6·22	1·8277699	6·70	1·9021075	7·18	1·9712993	7·66	2·0360119
6·23	1·8293763	6·71	1·9035989	7·19	1·9726911	7·67	2·0373166
6·24	1·8309801	6·72	1·9050881	7·20	1·9740810	7·68	2·0386195
6·25	1·8325814	6·73	1·9065751	7·21	1·9754689	7·69	2·0399207
6·26	1·8341801	6·74	1·9080600	7·22	1·9768549	7·70	2·0412203
6·27	1·8357763	6·75	1·9095425	7·23	1·9782390	7·71	2·0425181
6·28	1·8373699	6·76	1·9110228	7·24	1·9796212	7·72	2·0438143
6·29	1·8389610	6·77	1·9125011	7·25	1·9810014	7·73	2·0451088
6·30	1·8405496	6·78	1·9139771	7·26	1·9823798	7·74	2·0464016
6·31	1·8421356	6·79	1·9154509	7·27	1·9837562	7·75	2·0476928
6·32	1·8437191	6·80	1·9169226	7·28	1·9851308	7·76	2·0489823
6·33	1·8453002	6·81	1·9183921	7·29	1·9865035	7·77	2·0502701
6·34	1·8468787	6·82	1·9198594	7·30	1·9878743	7·78	2·0515563
6·35	1·8484547	6·83	1·9213247	7·31	1·9892432	7·79	2·0528408
6·36	1·8500283	6·84	1·9227877	7·32	1·9906103	7·80	2·0541237
6·37	1·8515994	6·85	1·9242486	7·33	1·9919754	7·81	2·0554049
6·38	1·8531680	6·86	1·9257074	7·34	1·9933387	7·82	2·0566845
6·39	1·8547342	6·87	1·9271641	7·35	1·9947002	7·83	2·0579624
6·40	1·8562979	6·88	1·9286186	7·36	1·9960599	7·84	2·0592388
6·41	1·8578592	6·89	1·9300710	7·37	1·9974177	7·85	2·0605135
6·42	1·8594181	6·90	1·9315214	7·38	1·9987736	7·86	2·0617866
6·43	1·8609745	6·91	1·9329696	7·39	2·0001278	7·87	2·0630580
6·44	1·8625285	6·92	1·9344157	7·40	2·0014800	7·88	2·0643278
6·45	1·8640801	6·93	1·9358598	7·41	2·0028305	7·89	2·0655961
6·46	1·8656293	6·94	1·9373017	7·42	2·0041790	7·90	2·0668627
6·47	1·8671761	6·95	1·9387416	7·43	2·0055258	7·91	2·0681277
6·48	1·8687205	6·96	1·9401794	7·44	2·0068708	7·92	2·0693911
6·49	1·8702625	6·97	1·9416152	7·45	2·0082140	7·93	2·0706530
6·50	1·8718021	6·98	1·9430489	7·46	2·0095553	7·94	2·0719132
6·51	1·8733394	6·99	1·9444805	7·47	2·0108949	7·95	2·0731719
6·52	1·8748743	7·00	1·9459099	7·48	2·0122327	7·96	2·0744290
6·53	1·8764069	7·01	1·9473376	7·49	2·0135687	7·97	2·0756845
6·54	1·8779371	7·02	1·9487632	7·50	2·0149030	7·98	2·0769384
6·55	1·8794650	7·03	1·9501866	7·51	2·0162354	7·99	2·0781907
6·56	1·8809906	7·04	1·9516080	7·52	2·0175661	8·00	2·0794414
6·57	1·8825138	7·05	1·9530275	7·53	2·0188950	8·01	2·0806907
6·58	1·8840347	7·06	1·9544449	7·54	2·0202221	8·02	2·0819384
6·59	1·8855533	7·07	1·9558604	7·55	2·0215475	8·03	2·0831845
6·60	1·8870697	7·08	1·9572739	7·56	2·0228711	8·04	2·0844290
6·61	1·8885837	7·09	1·9586853	7·57	2·0241929	8·05	2·0856720
6·62	1·8900954	7·10	1·9600947	7·58	2·0255131	8·06	2·0869135
6·63	1·8916048	7·11	1·9615022	7·59	2·0268315	8·07	2·0881534
6·64	1·8931119	7·12	1·9629077	7·60	2·0281482	8·08	2·0893918
6·65	1·8946168	7·13	1·9643112	7·61	2·0294631	8·09	2·0906287
6·66	1·8961194	7·14	1·9657127	7·62	2·0307763	8·10	2·0918640
6·67	1·8976198	7·15	1·9671123	7·63	2·0320878	8·11	2·0930984
6·68	1·8991179	7·16	1·9685099	7·64	2·0333976	8·12	2·0943306

No.	Logarithm	No.	Logarithm	No.	Logarithm	No.	Logarithm
8·13	2·0955613	8·61	2·1529243	9·09	2·2071748	9·57	2·2586332
8·14	2·0967905	8·62	2·1540851	9·10	2·2082744	9·58	2·2596776
8·15	2·0980182	8·63	2·1552445	9·11	2·2093727	9·59	2·2607209
8·16	2·0992444	8·64	2·1564026	9·12	2·2104697	9·60	2·2617631
8·17	2·1004691	8·65	2·1575593	9·13	2·2115656	9·61	2·2628042
8·18	2·1016923	8·66	2·1587147	9·14	2·2126603	9·62	2·2638442
8·19	2·1029140	8·67	2·1598687	9·15	2·2137538	9·63	2·2648832
8·20	2·1041341	8·68	2·1610215	9·16	2·2148462	9·64	2·2659211
8·21	2·1053529	8·69	2·1621729	9·17	2·2159372	9·65	2·2669579
8·22	2·1065702	8·70	2·1633230	9·18	2·2170272	9·66	2·2679936
8·23	2·1077861	8·71	2·1644718	9·19	2·2181160	9·67	2·2690282
8·24	2·1089998	8·72	2·1656192	9·20	2·2192034	9·68	2·2700618
8·25	2·1102128	8·73	2·1667653	9·21	2·2202898	9·69	2·2710944
8·26	2·1114243	8·74	2·1679101	9·22	2·2213750	9·70	2·2721258
8·27	2·1126343	8·75	2·1690536	9·23	2·2224590	9·71	2·2731562
8·28	2·1138428	8·76	2·1701959	9·24	2·2235418	9·72	2·2741856
8·29	2·1150499	8·77	2·1713367	9·25	2·2246235	9·73	2·2752138
8·30	2·1162555	8·78	2·1724763	9·26	2·2257040	9·74	2·2762411
8·31	2·1174596	8·79	2·1736146	9·27	2·2267833	9·75	2·2772673
8·32	2·1186622	8·80	2·1747517	9·28	2·2278615	9·76	2·2782924
8·33	2·1198634	8·81	2·1758874	9·29	2·2289385	9·77	2·2793165
8·34	2·1210632	8·82	2·1770218	9·30	2·2300144	9·78	2·2803395
8·35	2·1222615	8·83	2·1781550	9·31	2·2310890	9·79	2·2813614
8·36	2·1234584	8·84	2·1792868	9·32	2·2321626	9·80	2·2823823
8·37	2·1246539	8·85	2·1804174	9·33	2·2332350	9·81	2·2834022
8·38	2·1258479	8·86	2·1815467	9·34	2·2343062	9·82	2·2844211
8·39	2·1270405	8·87	2·1826747	9·35	2·2353763	9·83	2·2854389
8·40	2·1282317	8·88	2·1838015	9·36	2·2364452	9·84	2·2864556
8·41	2·1294214	8·89	2·1849270	9·37	2·2375130	9·85	2·2874714
8·42	2·1306098	8·90	2·1860512	9·38	2·2385786	9·86	2·2884861
8·43	2·1317967	8·91	2·1871742	9·39	2·2396452	9·87	2·2894998
8·44	2·1329822	8·92	2·1882959	9·40	2·2407096	9·88	2·2905124
8·45	2·1341664	8·93	2·1894163	9·41	2·2417729	9·89	2·2915241
8·46	2·1353491	8·94	2·1905355	9·42	2·2428350	9·90	2·2925347
8·47	2·1365304	8·95	2·1916535	9·43	2·2438960	9·91	2·2935443
8·48	2·1377104	8·96	2·1927702	9·44	2·2449559	9·92	2·2945529
8·49	2·1388889	8·97	2·1938856	9·45	2·2460147	9·93	2·2955604
8·50	2·1400661	8·98	2·1949998	9·46	2·2470723	9·94	2·2965670
8·51	2·1412419	8·99	2·1961128	9·47	2·2481288	9·95	2·2975725
8·52	2·1424163	9·00	2·1972245	9·48	2·2491843	9·96	2·2985770
8·53	2·1435893	9·01	2·1983350	9·49	2·2502386	9·97	2·2995806
8·54	2·1447609	9·02	2·1994443	9·50	2·2512917	9·98	2·3005831
8·55	2·1459312	9·03	2·2005523	9·51	2·2523438	9·99	2·3015846
8·56	2·1471001	9·04	2·2016591	9·52	2·2533948	10·00	2·3025851
8·57	2·1482676	9·05	2·2027647	9·53	2·2544446	11·00	2·3978952
8·58	2·1494339	9·06	2·2038691	9·54	2·2554934	12·00	2·4849065
8·59	2·1505987	9·07	2·2049722	9·55	2·2565411	15·00	2·7080502
8·60	2·1517622	9·08	2·2060741	9·56	2·2575877	20·00	2·9957322

TABLE OF NATURAL SINES, TANGENTS, SECANTS, &c.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
0	·000000	Infinite	·000000	Infinite	1·000000	1·00000	90
¼	·004363	229·1839	·004363	229·1817	1·000010	·999991	¾
½	·008727	114·5930	·008727	114·5887	1·000038	·999962	½
¾	·013090	76·39655	·013091	76·39001	1·000086	·999914	¼
1	·017452	57·29869	·017455	57·28996	1·000152	·999848	89
¼	·021815	45·84026	·021820	45·82935	1·000238	·999762	¾
½	·026177	38·20155	·026186	38·18846	1·000343	·999657	½
¾	·030539	32·74554	·030553	32·73026	1·000467	·999534	¼
2	·034900	28·65371	·034921	28·63625	1·000610	·999391	88
¼	·039260	25·47134	·039290	25·45170	1·000772	·999229	¾
½	·043619	22·92559	·043661	22·90377	1·000953	·999048	½
¾	·047978	20·84283	·048033	20·81883	1·001153	·998848	¼
3	·052336	19·10732	·052408	19·08114	1·001372	·998630	87
¼	·056693	17·63893	·056784	17·61056	1·001611	·998392	¾
½	·061049	16·38041	·061163	16·34986	1·001869	·998135	½
¾	·065403	15·28979	·065544	15·25705	1·002146	·997859	¼
4	·069757	14·33559	·069927	14·30067	1·002442	·997564	86
¼	·074109	13·49373	·074313	13·45663	1·002757	·997250	¾
½	·078459	12·74550	·078702	12·70621	1·003092	·996917	½
¾	·082808	12·07610	·083094	12·03462	1·003446	·996566	¼
5	·087156	11·47371	·087489	11·43005	1·003820	·996195	85
¼	·091502	10·92877	·091887	10·88292	1·004213	·995805	¾
½	·095846	10·43343	·096289	10·38540	1·004625	·995396	½
¾	·100188	9·981229	·100695	9·931009	1·005057	·994969	¼
6	·104529	9·566772	·105104	9·514365	1·005508	·994522	84
¼	·108867	9·185531	·109518	9·130935	1·005979	·994056	¾
½	·113203	8·833672	·113936	8·776887	1·006470	·993572	½
¾	·117537	8·507930	·118358	8·448957	1·006980	·993069	¼
7	·121869	8·205509	·122785	8·144346	1·007510	·992546	83
¼	·126199	7·923995	·127216	7·860642	1·008060	·992005	¾
½	·130526	7·661298	·131653	7·595754	1·008629	·991445	½
¾	·134851	7·415596	·136094	7·347861	1·009218	·990866	¼
8	·139173	7·185297	·140541	7·115370	1·009828	·990268	82
¼	·143493	6·968999	·144993	6·896880	1·010457	·989651	¾
½	·147809	6·765469	·149451	6·691156	1·011106	·989016	½
¾	·152123	6·573611	·153915	6·497104	1·011776	·988362	¼
9	·156435	6·392453	·158384	6·313752	1·012465	·987688	81
¼	·160748	6·221128	·162860	6·140230	1·013175	·986996	¾
½	·165048	6·058858	·167343	5·975764	1·013905	·986286	½
¾	·169350	5·904948	·171831	5·819657	1·014656	·985556	¼
10	·173648	5·758771	·176327	5·671282	1·015427	·984808	80
¼	·177944	5·619760	·180830	5·530072	1·016218	·984041	¾
½	·182236	5·487404	·185339	5·395517	1·017030	·983255	79½
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
10¾	·186524	5·361239	·189856	5·267152	1·017863	·982450	¼
11	·190809	5·240843	·194380	5·144554	1·018717	·981627	79
¼	·195090	5·125831	·198912	5·027340	1·019591	·980785	¾
½	·199368	5·015852	·203452	4·915157	1·020487	·979925	½
¾	·203642	4·910584	·208000	4·807685	1·021403	·979046	¼
12	·207912	4·809734	·212557	4·704630	1·022341	·978148	78
¼	·212178	4·713031	·217121	4·605721	1·023299	·977231	¾
½	·216440	4·620226	·221695	4·510709	1·024280	·976296	½
¾	·220697	4·531090	·226277	4·419364	1·025281	·975342	¼
13	·224951	4·445412	·230868	4·331476	1·026304	·974370	77
¼	·229200	4·362994	·235469	4·246848	1·027349	·973379	¾
½	·233445	4·283658	·240079	4·165300	1·028415	·972370	½
¾	·237686	4·207233	·244698	4·086663	1·029503	·971342	¼
14	·241922	4·133566	·249328	4·010781	1·030614	·970296	76
¼	·246153	4·062509	·253968	3·937509	1·031746	·969231	¾
½	·250380	3·993929	·258618	3·866713	1·032900	·968148	½
¾	·254602	3·927700	·263278	3·798266	1·034077	·967046	¼
15	·258819	3·863703	·267949	3·732051	1·035276	·965926	75
¼	·263031	3·801830	·272631	3·667958	1·036498	·964787	¾
½	267238	3·741978	·277325	3·605884	1·037742	·963631	½
¾	·271440	3·684049	·282029	3·545733	1·039009	·962455	¼
16	·275637	3·627955	·286745	3·487414	1·040299	·961262	74
¼	·279829	3·573611	·291473	3·430845	1·041613	·960050	¾
½	·284015	3·520937	·296214	3·375943	1·042949	·958820	½
¾	·288196	3·469858	·300966	3·322636	1·044309	·957571	¼
17	·292372	3·420304	·305731	3·270853	1·045692	·956305	73
¼	·296542	3·372208	·310508	3·220526	1·047099	·955020	¾
½	·300706	3·325510	·315299	3·171595	1·048529	·953717	½
¾	·304864	3·280148	·320103	3·123999	1·049984	·952396	¼
18	·309017	3·236068	·324920	3·077684	1·051462	·951057	72
¼	·313164	3·193217	·329751	3·032595	1·052965	·949699	¾
½	·317305	3·151545	·334595	2·988685	1·054492	·948324	½
¾	·321440	3·111006	·339454	2·945905	1·056044	·946930	¼
19	·325568	3·071554	·344328	2·904211	1·057621	·945519	71
¼	·329691	3·033146	·349216	2·863560	1·059222	·944089	¾
½	·333807	2·995744	·354119	2·823913	1·060849	·942642	½
¾	·337917	2·959309	·359037	2·785231	1·062501	·941176	¼
20	·342020	2·923804	·363970	2·747477	1·064178	·939693	70
¼	·346117	2·889196	·368920	2·710619	1·065881	·938191	¾
½	·350207	2·855451	·373885	2·674622	1·067609	·936672	½
¾	·354291	2·822538	·378866	2·639455	1·069364	·935135	¼
21	·358368	2·790428	·383864	2·605089	1·071145	·933580	69
¼	·362438	2·759092	·388879	2·571496	1·072952	·932008	¾
½	·366501	2·728504	·393911	2·538648	1·074786	·930418	½
¾	·370557	2·698637	·398960	2·506520	1·076647	·928810	¼
22	·374607	2·669467	·404026	2·475087	1·078535	·927184	68
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
22¼	·378649	2·640971	·409111	2·444326	1·080450	·925541	¾
½	·382683	2·613126	·414214	2·414214	1·082392	·923880	½
¾	·386711	2·585911	·419335	2·384729	1·084362	·922201	¼
23	·390731	2·559305	·424475	2·355852	1·086360	·920505	67
¼	·394744	2·533288	·429634	2·327563	1·088387	·918791	¾
½	·398749	2·507843	·434812	2·299843	1·090441	·917060	½
¾	·402747	2·482950	·440011	2·272673	1·092524	·915312	¼
24	·406737	2·458593	·445229	2·246037	1·094636	·913546	66
¼	·410719	2·434756	·450467	2·219918	1·096777	·911762	¾
½	·414693	2·411421	·455726	2·194300	1·098948	·909961	½
¾	·418660	2·388575	·461006	2·169168	1·101148	·908143	¼
25	·422618	2·366202	·466308	2·144507	1·103378	·906308	65
¼	·426569	2·344288	·471631	2·120303	1·105638	·904455	¾
½	·430511	2·322821	·476976	2·096544	1·107929	·902585	½
¾	·434445	2·301786	·482343	2·073215	1·110250	·900698	¼
26	·438371	2·281172	·487733	2·050304	1·112602	·898794	64
¼	·442289	2·260967	·493145	2·027799	1·114985	·896873	¾
½	·446198	2·241159	·498582	2·005690	1·117400	·894934	½
¾	·450098	2·221736	·504042	1·983964	1·119847	·892979	¼
27	·453991	2·202689	·509525	1·962611	1·122326	·891007	63
¼	·457874	2·184007	·515034	1·941620	1·124838	·889017	¾
½	·461749	2·165681	·520567	1·920982	1·127382	·887011	½
¾	·465615	2·147699	·526126	1·900687	1·129959	·884988	¼
28	·469472	2·130055	·531709	1·880727	1·132570	·882948	62
¼	·473320	2·112737	·537319	1·861091	1·135215	·880891	¾
½	·477159	2·095739	·542956	1·841771	1·137893	·878817	½
¾	·480989	2·079051	·548619	1·822759	1·140606	·876727	¼
29	·484810	2·062665	·554309	1·804048	1·143354	·874620	61
¼	·488621	2·046575	·560027	1·785629	1·146137	·872496	¾
½	·492424	2·030772	·565773	1·767494	1·148956	·870356	½
¾	·496217	2·015249	·571547	1·749637	1·151810	·868199	¼
30	·500000	2·000000	·577350	1·732051	1·154701	·866025	60
¼	·503774	1·985017	·583183	1·714728	1·157628	·863836	¾
½	·507538	1·970294	·589045	1·697663	1·160592	·861629	½
¾	·511293	1·955825	·594938	1·680849	1·163594	·859406	¼
31	·515038	1·941604	·600861	1·664280	1·166633	·857167	59
¼	·518773	1·927624	·606815	1·647949	1·169711	·854912	¾
½	·522499	1·913881	·612801	1·631852	1·172828	·852640	½
¾	·526214	1·900368	·618819	1·615982	1·175983	·850352	¼
32	·529919	1·887080	·624869	1·600335	1·179178	·848048	58
¼	·533615	1·874012	·630953	1·584904	1·182414	·845728	¾
½	·537300	1·861159	·637070	1·569686	1·185689	·843391	½
¾	·540975	1·848516	·643222	1·554674	1·189006	·841039	¼
33	·544639	1·836079	·649408	1·539865	1·192363	·838671	57
¼	·548293	1·823842	·655629	1·525254	1·195763	·836286	¾
½	·551937	1·811801	·661886	1·510835	1·199205	·833886	56½
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	De
33¾	·555570	1·799952	·668179	1·496606	1·202690	·831470	
34	·559193	1·788292	·674509	1·482561	1·206218	·829038	56
¼	·562805	1·776815	·680876	1·468697	1·209790	·826590	
½	·566406	1·765517	·687281	1·455009	1·213406	·824126	
¾	·569997	1·754396	·693725	1·441494	1·217068	·821647	
35	·573576	1·743447	·700208	1·428148	1·220775	·819152	55
¼	·577145	1·732666	·706730	1·414967	1·224527	·816642	
½	·580703	1·722051	·713293	1·401948	1·228327	·814116	
¾	·584250	1·711597	·719897	1·389088	1·232174	·811574	
36	·587785	1·701302	·726543	1·376382	1·236068	·809017	54
¼	·591310	1·691161	·733230	1·363828	1·240011	·806445	
½	·594823	1·681173	·739961	1·351422	1·244003	·803857	
¾	·598325	1·671334	·746735	1·339162	1·248044	·801254	
37	·601815	1·661640	·753554	1·327045	1·252136	·798636	53
¼	·605294	1·652090	·760418	1·315067	1·256278	·796002	
½	·608761	1·642680	·767327	1·303225	1·260472	·793353	
¾	·612217	1·633407	·774283	1·291518	1·264719	·790690	
38	·615662	1·624269	·781286	1·279942	1·269018	·788011	52
¼	·619094	1·615264	·788336	1·268494	1·273371	·785317	
½	·622515	1·606388	·795436	1·257172	1·277779	·782608	
¾	·625924	1·597639	·802585	1·245974	1·282241	·779885	
39	·629320	1·589016	·809784	1·234897	1·286760	·777146	51
¼	·632705	1·580515	·817034	1·223939	1·291335	·774393	
½	·636078	1·572134	·824336	1·213097	1·295967	·771625	
¾	·639439	1·563871	·831691	1·202369	1·300658	·768842	
40	·642788	1·555724	·839100	1·191754	1·305407	·766044	50
¼	·646124	1·547691	·846563	1·181248	1·310217	·763233	
½	·649448	1·539769	·854081	1·170850	1·315087	·760406	
¾	·652760	1·531957	·861655	1·160557	1·320019	·757565	
41	·656059	1·524253	·869287	1·150368	1·325013	·754710	49
¼	·659346	1·516655	·876977	1·140282	1·330071	·751840	
½	·662620	1·509161	·884725	1·130294	1·335192	·748956	
¾	·665882	1·501768	·892534	1·120405	1·340380	·746057	
42	·669131	1·494477	·900404	1·110613	1·345633	·743145	48
¼	·672367	1·487283	·908336	1·009142	1·350953	·740218	
½	·675590	1·480187	·916331	1·091309	1·356342	·737277	
¾	·678801	1·473186	·924391	1·081794	1·361800	·734323	
43	·681998	1·466279	·932515	1·072369	1·367328	·731354	47
¼	·685183	1·459464	·940706	1·063031	1·372927	·728371	
½	·688355	1·452740	·948965	1·053780	1·378599	·725374	
¾	·691513	1·446104	·957292	1·044614	1·384344	·722364	
44	·694658	1·439557	·965689	1·035530	1·390164	·719340	46
¼	·697791	1·433095	·974157	1·026529	1·396059	·716302	
½	·700909	1·426718	·982697	1·017607	1·402032	·713250	
¾	·704015	1·420425	·991311	1·008765	1·408083	·710185	
45	·707107	1·414214	1·00000	1·000000	1·414214	·707107	45
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	De

Table of Logarithmic Sines, Tangents, Secants, &c.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
0	− ∞	+ ∞	− ∞	+ ∞	10·00000	10·00000	90
¼	7·63982	12·36018	7·63982	12·36018	10·00000	9·99999	¾
½	7·94084	12·05916	7·94086	12·05914	10·00002	9·99998	½
¾	8·11693	11·88307	8·11696	11·88304	10·00004	9·99996	¼
1	8·24186	11·75814	8·24192	11·75808	10·00007	9·99993	89
¼	8·33875	11·66125	8·33886	11·66114	10·00010	9·99990	¾
½	8·41792	11·58208	8·41807	11·58193	10·00015	9·99985	½
¾	8·48485	11·51515	8·48505	11·51495	10·00020	9·99980	¼
2	8·54282	11·45718	8·54308	11·45692	10·00026	9·99974	88
¼	8·59395	11·40605	8·59428	11·40572	10·00034	9·99967	¾
½	8·63968	11·36032	8·64009	11·35991	10·00041	9·99959	½
¾	8·68104	11·31896	8·68154	11·31846	10·00050	9·99950	¼
3	8·71880	11·28120	8·71940	11·28060	10·00060	9·99940	87
¼	8·75353	11·24647	8·75423	11·24577	10·00070	9·99930	¾
½	8·78568	11·21432	8·78649	11·21351	10·00081	9·99919	½
¾	8·81560	11·18440	8·81653	11·18347	10·00093	9·99907	¼
4	8·84358	11·15642	8·84464	11·15536	10·00106	9·99894	86
¼	8·86987	11·13013	8·87106	11·12894	10·00120	9·99880	¾
½	8·89464	11·10536	8·89598	11·10402	10·00134	9·99866	½
¾	8·91807	11·08193	8·91957	11·08043	10·00149	9·99851	¼
5	8·94030	11·05970	8·94195	11·05805	10·00166	9·99834	85
¼	8·96143	11·03857	8·96325	11·03675	10·00183	9·99817	¾
½	8·98157	11·01843	8·98358	11·01642	10·00200	9·99800	½
¾	9·00082	10·99918	9·00301	10·99699	10·00219	9·99781	¼
6	9·01923	10·98077	9·02162	10·97838	10·00239	9·99761	84
¼	9·03690	10·96310	9·03948	10·96052	10·00259	9·99741	¾
½	9·05386	10·94614	9·05666	10·94334	10·00280	9·99720	½
¾	9·07018	10·92982	9·07320	10·92680	10·00302	9·99698	¼
7	9·08589	10·91411	9·08914	10·91086	10·00325	9·99675	83
¼	9·10106	10·89894	9·10454	10·89546	10·00349	9·99651	¾
½	9·11570	10·88430	9·11943	10·88057	10·00373	9·99627	½
¾	9·12985	10·87015	9·13384	10·86616	10·00399	9·99601	¼
8	9·14356	10·85644	9·14780	10·85220	10·00425	9·99575	82
¼	9·15683	10·84317	9·16135	10·83865	10·00452	9·99548	¾
½	9·16970	10·83030	9·17450	10·82550	10·00480	9·99520	½
¾	9·18220	10·81780	9·18728	10·81272	10·00508	9·99492	¼
9	9·19433	10·80567	9·19971	10·80029	10·00538	9·99462	81
¼	9·20613	10·79387	9·21182	10·78818	10·00568	9·99432	¾
½	9·21761	10·78239	9·22361	10·77639	10·00600	9·99400	½
¾	9·22878	10·77122	9·23510	10·76490	10·00632	9·99368	¼
10	9·23967	10·76033	9·24632	10·75368	10·00665	9·99335	80
¼	9·25028	10·74972	9·25727	10·74273	10·00699	9·99301	¾
½	9·26063	10·73937	9·26797	10·73203	10·00733	9·99267	79½
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	D
10¾	9·27073	10·72927	9·27842	10·72158	10·00769	9·99231	
11	9·28060	10·71940	9·28865	10·71135	10·00805	9·99195	79
¼	9·29024	10·70976	9·29866	10·70134	10·00843	9·99157	
½	9·29966	10·70034	9·30846	10·69154	10·00881	9·99119	
¾	9·30887	10·69113	9·31806	10·68194	10·00920	9·99080	
12	9·31788	10·68212	9·32747	10·67253	10·00960	9·99040	78
¼	9·32670	10·67330	9·33670	10·66330	10·01000	9·99000	
½	9·33534	10·66466	9·34576	10·65424	10·01042	9·98958	
¾	9·34380	10·65620	9·35464	10·64536	10·01084	9·98916	
13	9·35209	10·64791	9·36336	10·63664	10·01128	9·98872	77
¼	9·36022	10·63978	9·37193	10·62807	10·01172	9·98828	
½	9·36819	10·63181	9·38035	10·61965	10·01217	9·98783	
¾	9·37600	10·62400	9·38863	10·61137	10·01263	9·98737	
14	9·38368	10·61632	9·39677	10·60323	10·01310	9·98690	76
¼	9·39121	10·60879	9·40478	10·59522	10·01357	9·98643	
½	9·39860	10·60140	9·41266	10·58734	10·01406	9·98594	
¾	9·40586	10·59414	9·42041	10·57959	10·01455	9·98545	
15	9·41300	10·58700	9·42805	10·57195	10·01506	9·98494	75
¼	9·42001	10·57999	9·43558	10·56442	10·01557	9·98443	
½	9·42690	10·57310	9·44299	10·55701	10·01609	9·98391	
¾	9·43367	10·56633	9·45029	10·54971	10·01662	9·98338	
16	9·44034	10·55966	9·45750	10·54250	10·01716	9·98284	74
¼	9·44689	10·55311	9·46460	10·53540	10·01771	9·98229	
½	9·45334	10·54666	9·47160	10·52840	10·01826	9·98174	
¾	9·45969	10·54031	9·47852	10·52148	10·01883	9·98117	
17	9·46594	10·53406	9·48534	10·51466	10·01940	9·98060	73
¼	9·47209	10·52791	9·49207	10·50793	10·01999	9·98001	
½	9·47814	10·52186	9·49872	10·50128	10·02058	9·97942	
¾	9·48411	10·51589	9·50529	10·49471	10·02118	9·97882	
18	9·48998	10·51002	9·51178	10·48822	10·02179	9·97821	72
¼	9·49577	10·50423	9·51819	10·48181	10·02241	9·97759	
½	9·50148	10·49852	9·52452	10·47548	10·02304	9·97696	
¾	9·50710	10·49290	9·53078	10·46922	10·02368	9·97632	
19	9·51264	10·48736	9·53697	10·46303	10·02433	9·97567	71
¼	9·51811	10·48189	9·54309	10·45691	10·02499	9·97501	
½	9·52350	10·47650	9·54915	10·45085	10·02565	9·97435	
¾	9·52881	10·47119	9·55514	10·44486	10·02633	9·97367	
20	9·53405	10·46595	9·56107	10·43893	10·02701	9·97299	70
¼	9·53922	10·46078	9·56693	10·43307	10·02771	9·97229	
½	9·54433	10·45567	9·57274	10·42726	10·02841	9·97159	
¾	9·54936	10·45064	9·57849	10·42151	10·02913	9·97087	
21	9·55433	10·44567	9·58418	10·41582	10·02985	9·97015	69
¼	9·55923	10·44077	9·58981	10·41019	10 03058	9·96942	
½	9·56408	10·43592	9·59540	10·40460	10·03132	9·96868	
¾	9·56886	10·43114	9·60093	10·39907	10·03207	9·96793	
22	9·57358	10·42642	9·60641	10·39359	10·03283	9·96717	68
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	De

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
22¼	9·57824	10·42176	9·61184	10·38816	10·03360	9·96640	¾
½	9·58284	10·41716	9·61722	10·38278	10·03438	9·96562	½
¾	9·58739	10·41261	9·62256	10·37744	10·03517	9·96483	¼
23	9·59188	10·40812	9·62785	10·37215	10·03597	9·96403	67
¼	9·59632	10·40368	9·63310	10·36690	10·03678	9·96322	¾
½	9·60070	10·39930	9·63830	10·36170	10·03760	9·96240	½
¾	9·60503	10·39497	9·64346	10·35654	10·03843	9·96157	¼
24	9·60931	10·39069	9·64858	10·35142	10·03927	9 96073	66
¼	9·61354	10·38646	9·65366	10·34634	10·04012	9·95988	¾
½	9·61773	10·38227	9·65870	10·34130	10·04098	9·95902	½
¾	9·62186	10·37814	9·66371	10·33629	10·04185	9·95815	¼
25	9·62595	10·37405	9·66867	10·33133	10·04272	9·95728	65
¼	9·62999	10·37001	9·67360	10·32640	10·04361	9·95639	¾
½	9·63398	10·36602	9·67850	10·32150	10·04451	9·95549	½
¾	9·63794	10·36206	9·68336	10·31664	10·04542	9·95458	¼
26	9·64184	10·35816	9·68818	10·31182	10·04634	9·95366	64
¼	9·64571	10·35429	9·69298	10·30703	10·04727	9·95273	¾
½	9·64953	10·35047	9·69774	10·30226	10·04821	9·95179	½
¾	9·65331	10·34669	9·70247	10·29753	10·04916	9·95084	¼
27	9·65705	10·34295	9·70717	10·29283	10·05012	9·94988	63
¼	9·66075	10·33925	9·71184	10·28816	10·05109	9·94891	¾
½	9·66441	10·33559	9·71648	10·28352	10·05207	9·94793	½
¾	9·66803	10·33197	9·72109	10·27891	10·05306	9·94694	¼
28	9·67161	10·32839	9·72567	10·27433	10·05407	9·94593	62
¼	9·67515	10·32485	9·73023	10·26977	10·05508	9·94492	¾
½	9·67866	10·32134	9·73476	10·26524	10·05610	9·94390	½
¾	9·68213	10·31787	9·73927	10·26073	10·05714	9·94286	¼
29	9·68557	10·31443	9·74375	10·25625	10·05818	9·94182	61
¼	9·68897	10·31103	9·74821	10·25179	10·05924	9·94076	¾
½	9·69234	10·30766	9·75264	10·24736	10·06030	9·93970	½
¾	9·69567	10·30433	9·75705	10·24295	10·06138	9·93862	¼
30	9·69897	10·30103	9·76144	10·23856	10·06247	9·93753	60
¼	9·70224	10·29776	9·76580	10·23420	10·06357	9·93643	¾
½	9·70547	10·29453	9·77015	10·22985	10·06468	9·93532	½
¾	9·70867	10·29133	9·77447	10·22553	10·06580	9·93420	¼
31	9·71184	10·28816	9·77877	10·22123	10·06693	9·93307	59
¼	9·71498	10·28502	9·78306	10·21694	10·06808	9·93192	¾
½	9·71809	10·28191	9·78732	10·21268	10·06923	9·93077	½
¾	9·72116	10·27884	9·79156	10·20844	10·07040	9·92960	¼
32	9·72421	10·27579	9·79579	10·20421	10·07158	9·92842	58
¼	9·72723	10·27277	9·80000	10·20000	10·07277	9·92723	¾
½	9·73022	10·26978	9·80419	10·19581	10·07397	9·92603	½
¾	9·73318	10·26682	9·80836	10·19164	10·07518	9·92482	¼
33	9·73611	10·26389	9·81252	10·18748	10·07641	9·92359	57
¼	9·73901	10·26099	9·81666	10·18334	10·07765	9·92235	¾
½	9·74189	10·25811	9·82078	10·17922	10·07889	9·92111	56½
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

Deg.	Sine	Cosecant	Tangent	Cotangent	Secant	Cosine	Deg.
33¾	9·74474	10·25526	9·82489	10·17511	10·08015	9·91985	¼
34	9·74756	10·25244	9·82899	10·17101	10·08143	9·91857	56
¼	9·75036	10·24964	9·83307	10·16693	10·08271	9·91729	¾
½	9·75313	10·24687	9·83713	10·16287	10·08401	9·91599	½
¾	9·75587	10·24413	9·84119	10·15881	10·08531	9·91469	¼
35	9·75859	10·24141	9·84523	10·15477	10·08664	9·91336	55
¼	9·76129	10·23871	9·84925	10·15075	10·08797	9·91203	¾
½	9·76395	10·23605	9·85327	10·14673	10·08931	9·91069	½
¾	9·76660	10·23340	9·85727	10·14273	10·09067	9·90933	¼
36	9·76922	10·23078	9·86126	10·13874	10·09204	9·90796	54
¼	9·77182	10·22819	9·86524	10·13476	10·09343	9·90657	¾
½	9·77439	10·22561	9·86921	10·13079	10·09482	9·90518	½
¾	9·77694	10·22306	9·87317	10·12683	10·09623	9·90377	¼
37	9·77946	10·22054	9·87711	10·12289	10·09765	9·90235	53
¼	9·78197	10·21803	9·88105	10·11895	10·09909	9·90091	¾
½	9·78445	10·21555	9·88498	10·11502	10·10053	9·89947	½
¾	9·78691	10·21309	9·88890	10·11110	10·10199	9·89801	¼
38	9·78934	10·21066	9·89281	10·10719	10·10347	9·89653	52
¼	9·79176	10·20824	9·89671	10·10329	10·10496	9·89505	¾
½	9·79415	10·20585	9·90061	10·09939	10·10646	9·89354	½
¾	9·79652	10·20348	9·90449	10·09551	10·10797	9·89203	¼
39	9·79887	10·20113	9·90837	10·09163	10·10950	9·89050	51
¼	9·80120	10·19880	9·91224	10·08776	10·11104	9·88896	¾
½	9·80351	10·19649	9·91610	10·08390	10·11259	9·88741	½
¾	9·80580	10·19420	9·91996	10·08003	10·11416	9·88584	¼
40	9·80807	10·19193	9·92381	10·07619	10·11575	9·88425	50
¼	9·81032	10·18968	9·92766	10·07234	10·11734	9·88266	¾
½	9·81254	10·18746	9·93150	10·06850	10·11895	9·88105	½
¾	9·81475	10·18525	9·93533	10·06467	10·12058	9·87942	¼
41	9·81694	10·18306	9·93916	10·06084	10·12222	9·87778	49
¼	9·81911	10·18089	9·94299	10·05701	10·12387	9·87613	¾
½	9·82126	10·17874	9·94681	10·05319	10·12554	9·87446	½
¾	9·82340	10·17660	9·95062	10·04938	10·12723	9·87277	¼
42	9·82551	10·17449	9·95444	10·04556	10·12893	9·87107	48
¼	9·82761	10·17239	9·95825	10·04175	10·13064	9·86936	¾
½	9·82968	10·17032	9·96205	10·03795	10·13237	9·86763	½
¾	9·83174	10·16826	9·96586	10·03414	10·13411	9·86589	¼
43	9·83378	10·16622	9·96966	10·03034	10·13587	9·86413	47
¼	9·83581	10·16419	9·97345	10·02655	10·13765	9·86235	¾
½	9·83781	10·16219	9·97725	10·02275	10·13944	9·86056	½
¾	9·83980	10·16020	9·98104	10·01896	10·14124	9·85876	¼
44	9·84177	10·15823	9·98484	10·01516	10·14307	9·85693	46
¼	9·84373	10·15628	9·98863	10·01137	10·14490	9·85510	¾
½	9·84566	10·15434	9·99242	10·00758	10·14676	9·85324	½
¾	9·84758	10·15242	9·99621	10·00379	10·14863	9·85137	¼
45	9·84949	10·15052	10·00000	10·00000	10·15052	9·84949	45
Deg.	Cosine	Secant	Cotangent	Tangent	Cosecant	Sine	Deg.

INDEX.

"A" BRACKETS, 344
Absolute temperature, 406
Acceleration, 88
——— diagram, 83
Accommodation, passenger, 479
Accuracy of calculations, 6
Acid, dipping, 601
Acme screw threads, 358
Admiralty coefficient, 180-4
——— instructions re mild steel, 264
——— limiting size of plates, 237
——— riveting regulations, 289-92
——— tests (v. also *Tests*)
——— for cable, 528
——— chain, 529
——— materials, 263
——— s.w. rope, 578, 579
Advance (steering), 365
Aerodynamics, 406
——— biplane effects, 424
——— calculations for lift and drift, 427
——— centre of pressure, 414
——— distribution of pressure, 422
——— force on curved plates, 416
——— other bodies, 409
——— plates, normal, 406
——— inclined, 411
——— frictional resistance, 410
——— model experiments, 428
——— shape of edges, 421
Aeronautics, 431
——— description of airships, 431-8
——— envelope material, 445
——— tensions in, 447
——— form of airships, 444
——— lifting power, 436
——— model experiments, 438-444
Aeronautics, resistance, 438
——— stability, 435
Aeroplane, v. *Aerodynamics*
Aground, stability of ship, 142
Air and water, results in, 431
— circuits, power in, 398
— craft, wire rope for, 581
— efflux of, 400
— gap, effect of, 408
— movement of, 396-401
— quantity required, 399, 401
— resistance of, 397
— pressure on bodies, 409
——— plates, curved, 416
——— plane, 406-416
— ship, v. *Aeronautics*
— weight of, 396
Ale measure, 608
Algebraic symbols, 1
Alloys, table of, 259
Altitude of airships, 437
Aluminium bronze, 258
Amsler-Laffon integrator, 128
Anchor, cable attachment, 546
Anchors, tests and number of, 483, 526, 527, 530, 532
Angle bulb, weight, etc., 250
——— iron weight, 223
——— measurement of, 8
——— steel, weight, etc., 226, 246
Angular motion, 84
——— velocity, 82
Annealing, 257, 264, 294
Antilogarithm, 5
——— table, 704
Apothecaries' weight, 606
Apparent wave period, 149
Appendage, 96
——— (airships), 442
——— resistance, 162
Arc, circular, 22, 23, 60
Ardency, 208
Area of circles (table), 647
——— figures, general rules, 42-8
——— geometrical figures, 36-41
——— midship section, 91
——— sections, 91
——— segments of circle (table), 652
——— surfaces, v. *Surface*
Armament particulars, 108, 380-8
Armour, 108, 378, 388

Armour bars, air resistance, 398
—— bolts, 388
Armstrong guns, 380
Aspect ratio, 411 ff.
Atwood's formula, 115
Avoirdupois weight, 606
Axis of rolling, 151

BABBIT'S white metal, 258
Backstay, screw for, 545
Baggage, 108
Balance of rudders, 366
Ball-bearing friction, 363
Ballast for inclining experiment, 138
Ballistics, 380-8
Ballonet, 432
Balloon, v. *Aeronautics*
Balls, weight of cast iron, 234
Barges, towing data, 195
Barnes' method for stability, 118-124
Bars, round, elliptic, square, etc., weight, 222
Bath, size of, 556
Beam, determination of, 391
—— effect on speed 172
—— stability, 129
Beam, B.M. and S.F., general 300-8
—— graphical, 303-8
—— B.M. and deflection, 301-8, 322, 323
—— continuous, distribution of load, 320
—— supports to, 322
—— of equal strength, 320, 321
—— stress due to bending, 312
—— shear, 332
—— strongest cut from log, 29
—— unsymmetrical, 326
Beams, scantlings of, 508, 517, 522, 524
Bearing pressure on screw, 356
—— values of rivets, 286-8
Bearings, friction of, 363
—— shaft, distance between, 335
—— working pressure on, 335, 370, 371
Beaufort scale for winds, 210
Beer measure, 608
Bell mouths to trunking, 399
Belt gearing, 357-9
—— length of, 357
—— strength on slip of, 357-9
Bend in pipe, 404
Bend in trunk, 397
Bending moment, airship, 448
—— beam, 300-8, 322, 323
—— equivalent on shafts, 332
—— launching, 376
—— rudder head, 370
—— ship, 345-48
Berths, 478, 503
Bilge keel, 154
Bilging, effect of, 140-2.
Biplane, 424
Bituminous paint, 595
Blade, area of screw, 191
Blake's stopper, 540
Blechynden's formula, 167
Block coefficient, 93
Blocks, cathead, 552
—— engineers' tackle, 558
—— galvanized, 569
—— leading, 550
—— lift and snatch, 542, 570
—— miscellaneous, 571
—— snatch, 542, 570
—— Weston, differential, 355, 567
Board of Trade regulations—
Machinery, boilers, 450-58
—— distillers, 466
—— evaporators, 458
—— furnaces, 457
—— materials, 448
—— mountings, 462
—— refrigerators, 465.
—— safety valves, 459
—— shafts, 464
—— spare gear, 463
—— steam pipes, 459
—— superheaters, 458
Motor launches, 468
—— vessels, 466
Ships, anchors 527
—— cables, 528
—— certificates (various), 469
—— compasses, 477
—— distress signals, 477
—— emigrant, 400, 502
—— fire appliances, 476
—— hawsers, 576, 577
—— life-saving appliances, 495
—— master's and crew's spaces, 477
—— passenger accommodation, 479
—— plying limits, 469
—— pumps, 475
—— steering gear, 475
—— ventilation, 400
Boats, number and complement, 495

Boats, passengers allowed in, 483
——— scantlings and weights, 564, 565
——— slings for, 399
Bobstay, 586-9
Boiler mountings, 462
Boiler-rooms, size of, 389
——— air required, 399
Boilers, iron, rules for, 458
——— steel, rules for, 450
——— tests for, 448
Bolt, armour, 108, 388
—— deck, 556
—— screwed, strength of, 339
—— steel, tests for, 270
Boltheads, weight of, 236
Bolt rope cordage, 574
Bonjean curves, 345, 373
Bow lights, 487
Bowsprits, 586, 590, 592
Box couplings, 335
Braced structures, 294-9
Brass, 257, 279
——— (Naval), v. *Naval brass*
——— plate, weight of, 230
Breadth (Lloyd's), 507, 520
Bricklaying, 561
Bridges, scantlings of, 510, 514
Bristol Channel, distances down, 215
British Corporation rule for rudders, 371
——— Standard keys and keyways, 339, 340
——— screws and pipes, 533-7
——— sections, 241-54
——— bulb angles, 250
——— tees, 253
——— channels, 244
——— equal angles, 246
——— I-beams, 242
——— tees, 252
——— unequal angles, 248
——— zeds, 254
——— thermal unit, 405
——— tonnage, 490
Bronze, 257
Builders' O.M. tonnage, 494
Bulb angles, 230
—— tees and plates, 253
Bulk modulus, 310
Bulkheads, Committee's report, 483
——— Lloyd's rules, 508, 516
——— number required, 478
Bulkheads, strength and deflection, 322, 324, 483
——— weight and C.G., 104
Bullivant's S.W. rope, 580-2
——— winch (crab), 583
Bulwarks, height of, 469, 479, 481
Bunks and berths, 478, 503
Buoyancy, 89
——— airships, 437
——— centre of, v. *Centre of buoyancy*
——— curve of, 112, 113, 316
——— lifeboats, 498
Butts and straps, 289, 290, 521

CABLE, attachment to anchor, 546
——— iron tests, 275
——— link, proportions of, 538, 555
——— provision of and tests for, 526, 528, 532, 534
——— stowage, 544
Calculations, numerical, 6
Calculus, differential and integral, 19-21
Camber of launching ways, 378
Canvas, 282, 283
Cargo, allowable, 505
Carlisle Bridge, distances from, 214
Carrigaloe Ferry, distances from, 215
Cask gauging, 604, 613
Cast iron, 255, 276, 458
——— balls, weight, 234
——— pipes, weight, 233
——— teeth, 342
——— steel, 256, 272, 285, 450
Castings, shrinkage of, 235
Cat chain, 529, 538
Catenary, 15-18, 27
Cathead block, 552
Cattle, 482, 505
Caulking, wood, 597
Cavitation, 192
Cement, 602
Centigrade, 406
Centre of buoyancy, 89, 91, 112-14
——— longitudinal, 132
——— shift due to trim, 133
——— effort, 208
——— flotation, 96, 131, 132
——— gravity, rules for, 62-9
——— geometrical figures, 59-62
——— hull, 107
——— masses, 79

Centre of gravity, ships, 108-9, 118
——— lateral resistance, 208
——— percussion, 87
——— pressure (hydrostatical), 89
——— (moving in air), 414, 418, 422
——— (moving in water), 369
Centrifugal force, 87, 358
Certificate, Board of Trade, 469
Chain (catenary), 15-18
——— for blocks, 567
——— proportions of link, 528
——— weight and tests, 529
Channels (British Standard), 244
Characteristic (logarithm), 4
Charge, weight, etc., 380-7
Chrome vanadium steel, 258
Circle, area and circumference, rules, 37, 38
——— table, 642, 647
——— properties, 39
Circular arc, 22, 23, 60
——— bars, v. *Round*
——— measure, 8
——— table, 639
——— ring, flat, area, 40
——— sector, area, 40
——— C.G., 61
——— segment, area, 40
——— (table), 652
——— C.G., 61
——— zone, area, 40
Circumference of circle (table), 642
Clear hawse slip, 554
Cleat, belaying, 512, 554
Closet, v. *Water closet*
Clyde, distance down, 213
Coal, effect on bilging, 140
——— endurance, 189
——— measure, 608
——— per H.P. per hour, 390
——— stowage and weight, 103
Coamings, 509
Coefficient of air resistance, 406
——— fineness, 93
——— friction, 358, 363, 376, 377
——— propulsion, 161, 163
——— rigidity, 310
Coins, English, 633
Coir rope, 572
Coke measure, 609
Collisions, prevention of, 487
Colours for drawings, 565
——— harmony of, 596
Columns, strength of, 328
Committee, Bulkhead, recommendations, 483
Comparison, Law of, 169, 184, 428
Compartment, time to empty, 400, 403
Compass, points of, 636
——— provision of, 477, 482
Complement of an angle, 7
Compound pendulum, 87
Compressive strength and stress, 328-31
Conduction of heat, 405
Cone, air resistance, 409
——— C.G., 61
——— development, 30
——— volume, 49
——— of frustrum, 50
Conic sections, 13, 27
Conservation of energy, 85
Constant system of notation, 176
Consumption of fuel, 390
Convection of heat, 406
Copper, 257, 279
——— pipes, weight, 235, 459
——— plates, weight, 230
——— rods, weight, 234
Cordage, hemp, 572
——— manilla, 283, 573
——— various, 574
Corn measure, 608
Cornish, Dr. Vaughan, wave dimensions, 148, 149
Corresponding speeds, 169, 428
Cosecant, cosine, 7
——— (table), 716
Cotangent, 7
——— (table), 716
Cotton fabric for airships, 447
Countersinking, 265, 291
Couple, mechanical, 77
Couplings, 335
Course, indication of, 490
——— of ship turning, 364
Coventry Ordnance Co., guns, 386
Coversed sine, 7
Cowl, 400
Crab winch, 583
Cranes, hand and steam, 362
Creosoting timber, 558
Crew space, 477
Critical angle, 412, 416
Cross curves of stability, 117
Crosshead for davit, 546
Cube, cube root (table), 655
Cubic measure, 607, 614
Curvature, radius of, 20
Curve of buoyancy, 112, 113
——— displacement, 92
——— metacentres, 112
——— midship section areas, 91
——— sectional areas, 91, 173, 393
——— tons per inch, 92

Curved plates, pressure on, 416
Cwt. and kilogrammes (table), 625
——— tons (table), 629
Cycloid, etc., 18, 33
——— area, 41
Cylinder, air resistance, 409
——— C.G., 61
——— development, 30
——— stability, 128
——— strength, 330, 331, 457-9
——— surface and volume, 49
Cylindrical ring, 51

DAVIDSON, Messrs., fans, 395
Davit, Admiralty tests, 263
——— diameter required, 326
——— fittings, 546
——— number and positions, 495-502
Deadweight, 494
Deadwood, effect on steering, 366
Decimals of a foot and yard, 630
——— an inch, 631
Deck, Lloyd's rules for, 509, 514, 517
——— bolt, 556
——— bulkhead, 486
——— coaming, 509
——— pipe, 538
——— planking, 478, 503, 509, 519, 522, 524
——— weight of, 106
Decks, height between, 478, 481, 503
Declivity, building and launching, 378
Definite integral, 21
Deflection of beams, 322, 327
——— bulkheads, 321
——— plating under lateral pressure, 325
Degree (angular), 8
Denny's formula for wetted surface, 167
Density (v. also *Weight*), 88
Depth (Lloyd's), 507
Derrick strength and stability, 296
Design notes, 391-4
Detrimental surface, 427
Devonport, distances around, 221
Diameter of screw propeller, 190-5
Diaphragm in pipe, 404
Differential block, 567
——— calculus, 19
Dimensions, determination of (design), 391
——— effect of addition of weight, 392
Dimensions, increased speed, 392
——— change on stability, 129
Dipping acids, 601
Direct method for stability, 125
Disc area ratio, 191, 193
Discharge through an orifice (air), 400
——— (water), 403
Discount table, 634
Dispensary, 504
Displacement, 90
——— (appendages), 96
——— curve, 92
——— effect on resistance, 169
——— launching, 374
——— out of trim, 132
——— sheet, 94-102
——— and tonnage, 493
Distances, Bristol Channel, 215
——— Carlisle Bridge to Wicklow Head, 214
——— Carrigaloe Ferry to Roche Pt., etc., 219
——— Clyde, 213
——— Devonport to Portland Bill, 221
——— foreign ports, 594
——— Humber, 218
——— Liverpool to Holyhead, 216
——— measurement of, 28, 29
——— measured (principal), 201
——— Southampton and Isle of Wight, 220
——— Thames, 212
——— Tyne, 217
Distemper, 596
Distiller, regulations, 465
Distress signals, 469, 477, 490
Division of a line, 22
Dock gates, 339
Docking, effect on stability, 143
Donkey-engine, 463
Door (v. also *W.T. Door*), 474, 503
——— screw for, 356
Double bottom, 486, 487, 507
Draught at perpendiculars, etc., 131-3
——— change in fresh water, 132
——— effect of addition of weight or increase of speed in design, 392
——— effect on stability, 129
——— steering, 366
——— to read accurately, 138

Drawing papers, sizes of, 613
Drawings, colours for, 565
Drift, 412, 429
Drilling, effect on strength, 294
Driving power, 209
Drum for s.w. rope, 575, 580
Dry measure, 608
Dryers, 596
Dunmore, distances from, 219
Duodecimals, 559
Duralumin, 258, 434
Dynamical stability, 115, 116, 124
Dynamics, 84

e (base of natural logarithms), 8
Earths, rocks, etc., 636
Eccentrically loaded pillars, 329
Eccentricity (ellipse, etc.), 14
Economical speed, 190
Edge strips and laps, 289, 290
Effective horse-power, 161
Efficiency, aerodynamical, 412
——— hull, 164
——— propeller, 191, 192
——— propulsive, 162
——— screw, 355
Efflux of air, 400
Effort, centre of, 208
Elastic coefficients, 309
——— limit, 309
Elasticity, modulus of, 260, 310, 311
Elbow in pipe, effect of, 404
Ellipse, 14, 23-5
——— area, 41
——— momental, 73
——— perimeter, 49
Ellipsoid, volume, 51, 52
——— volume of frustrum, 52
Elliptical spring, 336
Elswick Ordnance Co., guns, 380
Emigrant ships, 502
Enamels, 595, 603
Energy, 85
Engineers' tackle blocks, 568
Engine-room, air for, 400
——— size, 389
English weight, etc., 606-12
——— comparison with metric, 615-38
Entablature plate, 82
Envelope, airship, 437, 445
Epicycloid, 18, 34
Equipment, 108, 469, 476, 482, 530, 532
——— of boats, 500
——— yachts, 526
Equivalent bending and twisting moments, 332

Evaporators, rules concerning, 458
Evolute of curve, 18
Excursion limits, 469
Expansion due to heat, 405
Experiment for finding stability, 135-8
Exponential functions (table), 708
Extinction of rolling, 152-4
Eyebolt, eyeplate, 554

FABRIC, airship, 447
Factor of safety, 286, 309 311, 329, 450
Fahrenheit thermometer, 406
Fans, ventilating, 395
Fastenings for wood yachts, 521
Fastnet, distances, 219
Feathering paddles, 197
Feed heaters, 458
Feet to inches and yards (table), 630
——— metres and millimetres, 624
Fenton's white metal, 258
Figure of merit, 378
Fine screw threads (B.S.), 536
Fineness, coefficient of, 93
Fire, prevention of, 468, 469, 476
Fittings, ship, 538-56
Five-eight rule, 46
Flanges of couplings, 335
——— pipe (B.S.), 534
Flat steel, weight, 224
— surfaces, pressure on, 325, 454, 458
Flexible steel wire rope, v. *Rope*
Float area for paddles, 196
Floats, number of (paddles), 196
Flotation, centre, 96, 131, 132
Flow of water through pipes, 403
Flywheel, stress in, 328
Focus of conic, 23-5
Fog signals, 489
Force and motion, 84
——— resolution of, 76-9
Forced and free rolling, 156
Foreign measures, weights, etc., 609-38
Forged steel, tests, 270-2 285, 450
Forgings, wrought iron, tests, 274
Form, determination of ships, 393
——— of airships, 444
Four-way piece, volume, 56
Frames, 507, 522
——— plate, design of, 333
——— weight and C.G., 104
Framework, stresses in, 295
Framing of airships, 434
Freeboard, 469, 520
——— of lifeboats, 498
Freeing ports, 479, 481

Frequency of vibration, 86, 337
Fresh-water allowance, 108
——— effect on draught, 132
Friction, air in trunks, 397
——— belting, 358
——— coefficients of, 358, 363, 376, 377
——— journals and pivots, 363
——— water in pipes, 404
Frictional resistance in air, 410, 439
——— of ships, 165-8
Froude, R.E., propeller data, 190
——— W., law of comparison, 169
Fuel, oil, density, 108
—— per H.P. per hour, 390
Funicular polygon, 302
Furnaces, 457

g, 8, 84-6
Galvanizing, 605
Gauges, plate and wire, 238, 239
Gauze, air resistance, 409
Geometry, practical, 22
Girders for flat surfaces, 455
——— plate web, 333
Girth, mean, 167
——— of yachts, 520
Graphical, S.F. and B.M., 303-8
Gravity, motion under, 85
Glue, 602
Grease for launching, 376, 378
Greek alphabet, 8
Gross tonnage, 490-93
Grounding, effect on stability, 143
Gudgeons, 371
Gunfire, heel due to, 155
Gunmetal, 257, 278, 458
Guns, particulars of, 379-88
Gyration, radius of, 69 (v. *Moment of inertia*).

HAMMOCK cloths, 596
Harmony of colours, 596
Hatches, W.T., 474
Hawse pipe, 538
Hawsers, manilla and hemp, 573, 582
——— provision of, 526, 531
——— S.W., data concerning, 576, 577
Head (of air), 397
Heat (conduction, etc.), 405, 406
——— generated in journals, 363
——— specific, 405
Heel due to added weight, 134
——— gunfire, 155
Height between decks, 478, 481, 508
Heights of bridges, useful, 579
Helical spring, 337
Helm, v. *Steering*
——— angle, 366
Hemisphere, etc., C.G., 61
Hemp rope, 572, 582
High tensile steel, tests, 266, 269
Hollow and full lines, 174-6
——— pillars, strength of, 328
Holyhead to Liverpool, distances, 216
Hook, strength and form of, 338
Hooke's joint, 361, 549
Hoop-iron, weight, 236
Horizon, dip and distance of, 36
Horse, work done by, 360
Horse-power, 85
——— of air, 398
——— of ships, v. *Speed*
——— transmitted by teeth, 343
Hospital, ship's, 401, 504
Hull efficiency, 162-4
—— survey of, 473
—— weight and C.G., 103-7
Humber, distances down, 218
Hundredweights and kilogrammes (table), 625
——— tons, 629
Hydraulic test of boilers, 448
Hydrogen, properties of, 436
Hydrostatics, 88
Hyperbola, 14, 25, 26
——— rectangular, 15, 27
——— area of, 41
Hyperbolic functions, 13
——— (table), 708
——— logarithms, 4
——— (table), 711
Hypocycloid, 18
——— to draw, 35

I BARS, weight and properties, 242
Ignition, 467
Impact, 88
Impregnation of timber, 558
Inaccessible objects, distances, 28, 29
Inches, decimals and fractions (table), 631
——— to feet and yards (table), 630

Inches to metres (table), 622
——— millimetres (table), 615, 623
Inclined plane, 85, 354
——— plate, air pressure on, 411
Inclining experiment, 135-8
Index of speed at which resistance varies, 166, 169
Indiarubber, 281
Indicated horse-power, 161
Inertia, moment of, v. *Moment of inertia*
Ingot steel forgings, 271, 285
Ink, 604
Inlets, air, 396-401
Inner bottom, 486
Insulation, heat, 405
Integral calculus, 20
——— definite, 21
Integrator, 126
International rules for prevention of collisions at sea, 487
Inverse functions, 19
Involute curves, 18
——— of a circle, 85
Iron, v. *Metal, Cast iron, Pig iron, etc.*
—— boilers, 458
—— cable, tests, 275
—— hoop, weight, 230
—— in place of steel, 285
—— ore, 255
—— pipes, weight, 232
Irreversible screws, 356
Isle of Wight, distances, 220

JOHNS, A. W., aerodynamics, 406
——— aeronautics, 431
——— curves of resistance, 188
——— dimensions of A brackets, 344
Joint, universal (Hooke's), 361, 549
Joints in a perfect frame, 294
——— riveted, 285
Joule's equivalent, 405
Journal, friction of, 363
Judgment items, 103, 107

KEEL, 507, 522, 524
Keys and keyways (British Standard), 339
Kilogrammes and oz., lb., qrs., cwt., and tons (table), 625, 626
Kilometres and nautical miles, 200
Kinetic energy, 85
Kingston valves, 462
Knots and kilometres (table), 200
——— statute inches (table), 199
——— time (speed tables), 202

LACQUER, 600
Ladders, companion, 604
Lagging (heat), 405
Land measure, 606, 607
Lapped butts and edges, dimensions, 289, 290
Lateral resistance, centre of, 208
Launch, motor, 468
——— passengers allowed in, 483
Launching calculations, 372-6
——— declivities and friction, 377
——— general, 372-8
——— of *Lusitania* and *Mauretania*, 376
——— stresses, 375
——— weight of ships, 374
Law of comparison, 169, 184
Lead, 280
——— line, 476
——— pipes, weight, 234
——— plates, weight, 230
Leading block (anchor gear), 550
Leakage of air, 400
Leather belting, 358
Length, cable, 538
——— circular arc, 22, 37
——— curves (general), 48, 49
——— determination of ship's, 391
——— effect on speed, 170-2
——— entrance and run, 172-5
——— evolutes, 49
——— favourable, 171
——— Lloyd's, 507, 520
——— of rivets for ordering, 292
——— of waves, 146, 148
Lever, 353
Lifeboats, 495-502
Lifebuoys and jackets, 497
Life-rafts, 500
Iife-saving appliances, 469, 495-502
Lift (aerodynamical), 412, 429
—— position of, when launching, 375
Lift-drift ratio, 417 ff.
Lifting power of airships, 436
Lighting, electric, etc., 479, 504

Lights for lifebuoys, 477
——— required at sea, 487
Lilley's formula for pillars, 328
Limits for plying, 469
Line, curved, C.G., 60, 62
Lineal measure, 606, 613
Lines, preparation of, 393
Link, proportion of, 538
Links, end and enlarged, for cable, 555
Liquids, density of, 262
Liverpool to Holyhead, distances, 216
Lizard Point, distances, 221
Lloyd's rules for anchors and cables, 530-2
——— hawsers (S.W.), 576, 577
——— masts and rigging, 584-93
——— riveting, 289-92
——— shafts, 506
——— ships, 507-19
——— yachts, 520-6
——— tests for ship materials, 284
Load of timber, 561, 636
Loads, curve of vessels, 317
——— of beams, 301
Logarithmic series, etc., 10
——— (table), 720
Logarithms, 4
——— (table), 700
——— hyperbolic (table), 711
London, distances near, 212, 594
Long measure, 606, 613
Longitudinal number (Lloyd's), 507
——— stability, 131-4
Lubrication, effect on friction, 363
Lusitania, particulars of launch, 376

MACHINERY, Board of Trade rules for, 448
——— spaces, air for, 399-401
——— deduction from tonnage, 492
——— weights, space, etc., 108, 388-90
Magazines, air for, 400
Malleable cast iron, 255, 273, 276, 277
Manchester Ship Canal, 579
Manganese bronze, 258
Manilla cordage, 283
——— hawser, 573
Mantissa, 4
Marking of ship, 494
Master's and crew spaces, 477
Masts, Lloyd's rules for, 590, 592
Materials, notes on, 255 ff.
——— weight and dimensions, 222 ff.
——— strength, 262
Mauretania, launching data, 376
Mean girth, Blechynden's, 167
Mean of means, 197
Measure, timber, 559
Measured miles, principal, 201
——— speed tables, 202
——— trials on, 197
Measures, comparison English and metric, 615-38
——— English, 606
——— foreign and English, 632
——— metric, 613
——— miscellaneous, 609-12
Mechanical powers, 353-63
Melting-points of metals, 405
Men, space occupied by, v. *Passengers*.
——— strength of, 360
——— weight of, 108, 109
Messing space, air required for, 399-401
Metacentre, 95, 111-14
——— longitudinal, 95, 133
——— transverse, 95, 101
Metacentres, curve of, 113
Metacentric diagram, 112, 113
——— height, 112, 114
Metal sheets, weight, 230
Metals, conducting power of, 405
——— expansion of, 405
——— weight and strength, 260
Metres to feet, 621
——— inches, 622
Metric system, 613, 614
——— comparison with English, 615-38
Midship section area, 91
——— coefficient, 93
Mild steel, Admiralty instructions, etc., 264
——— tests, 265, 268, 284, 449
Miles, tables of measured, 47
——— nautical, and kilometres (table), 200
——— statute (table), 199
Millimetres to feet (table), 621
——— inches (table), 615, 623
Miscellaneous constants, 223
——— substances, weight, and strength, 262

Mixing paint, 596
Model experiments, aeroplanes 428
——— airships, 438
——— ships, 176
Modulus of elasticity, 260, 261, 310, 311
——— section, 313
——— solid and hollow shafts, 318, 319
Moments of figure, *v. Centre of gravity.*
——— force or couple, 77-9
——— inertia, 69-72, 89
——— about various axes, 70, 72-4
——— B.S. sections, 241-54
——— circular sections (table), 349-52
——— geometrical figures, 75, 313-17
——— polar, 72
——— ships, 150-9, 349-352
——— waterplane, 94, 99, 112, 133
——— resistance, 313 ff.
——— stability, 115
——— weights, 80
——— to change trim one inch, 133, 134
Momental ellipse, 73
Momentum, 84
——— angular, 84, 87
Money, foreign and English, 632
——— table, 638
Mooring chain, formulæ for, 16-18
Moseley's formula, 115
Motion, 81
Motor-boats, 498, 565
——— and engines, rating, 388
——— launches, 468, 565
——— vessels, 466
Mountings and guns, 379
Muntz metal, 257
Muzzle velocity of projectiles, 379-88

NAVAL brass, 258, 277, 278
Net, suspended in stream, 16
Net tonnage, 492, 493
Neutral axis, 313
Newall's steel wire rope, 575-7
Newcastle-on-Tyne, distances, 213
——— high-level bridge, 578
Nickel steel, tests, 267, 270
Normal to curve, 19, 22, 24
Normand's formulæ, 114, 134
Numbers, miscellaneous, 612
——— useful, 637
Nuts, sizes, 535
——— weight, 236

OAKUM, 597
Observations of rolling, 160
Oil fuel, effect on stability, 140
——— per H.P. per hour, 390
——— weight, 108, 140
Oil tanks, 466
Open link chain, 538
Openings in boilers, 454
Ordnance, particulars of, 380-7
Ore, iron, 255
Orifice, flow of water through, 402
Ounces and kilogrammes (table), 625
——— pounds (table), 629

PADDLES, 196, 197
Paint mixing, 596
——— quantity required, 535, 597
Painting, etc., 595-605
Panama Canal tonnage, 493
Paper, size of, 613
——— tracing, 604
Parabola, 18, 25
——— area, 41
——— C.G., 61
——— of various orders, area, 42, 43
Parabolic cylinder, stability, 128
——— half segment, C.G., 61
Paraboloid, C.G., 61
——— development, 32
——— and frustrum, volume, 52, 58
Paraffin, consumption of, 390
Parallel forces, 77, 78
——— plates, air pressure, 424
Parallelogram, area, 36
Parallelopiped, C.G., 61
——— surface, 49
Passenger accommodation, 479
Passengers, number and space, 468, 479-83, 499, 502, 504
——— weight and C.G., 109
Pence and shillings (table), 638
Pendulum, compound, 87
——— errors when measuring rolling, 160

Pendulum period over large arcs, 86
—— simple, 86
Percussion, centre of, 87
Perforation of armour, 378, 388
Perimeter of ellipse, 49
Period of dipping, 151
—— pitching, 159
—— rolling, 150-3
—— vibration, 337
Permeability of airship envelopes, 437
Perpendicular, to draw, 22
Petrol consumption, 390
Phosphor bronze, 258, 279
Pi (π), 3, 39, 637
Pig iron, 255
Pillar, strength of, 328
Pillars, Lloyd's rules for, 509, 515, 521-4
Pintle, rudder, 370, 371
Pipe flanges, 534
—— threads, 537
Pipes, bilge suction, 487
—— deck and hawse, 528
—— flow of water through, 403
—— oil or petrol, 467
—— weight, 223, 232-5
Piping fourway, volume, 61
Pitch and pitch ratio, 190-5, 356
—— for caulking, 597
—— of rivets, 289
Pitched chain, 529
Pitching, 159
Pivot, friction of, 363
Pivoting point, 365
Planking, outside, 524
—— weight, 222
Plastering, 561
Plate gauges, 238
—— limiting sizes (Admiralty), 237
—— pressure on, in air, 406 ff.
—— —— water, 368
—— rudder, thickness of, 371
—— web girder, 333
Plating, compressive stress allowable, 330
—— Lloyd's rules, 509, 518, 521-4
—— stress due to bending, 312
—— —— lateral pressure, 325, 454
—— weight, 222, 230
—— —— and C.G., 104
Plying limits, 469
Plymouth, distances near, 221
Points of the compass, 636
Poisson's ratio, 310
Polar co-ordinates, 46, 65
—— moment of inertia, 72
Polygon, area, 36, 37
Polyhedron, volume and surface, 51
Pontoon lifeboats, 498
Portland Bill, distances near, 221
Ports, distances from London, 594
Potential energy, 85
Poundal, 84
Pounds and kilogrammes (table), 625, 626
—— ounces (table), 628
—— tons (table), 628
Power, 85
—— air circuits, 398
—— alteration due to change of speed, 392
—— increase due to additional resistance, 201
—— to carry sail, 209
—— transmitted by belting, 358
Powering ships, v. *Speed*
Powers, table of two-thirds, 184
Preservation of timber, 558
Pressure, air, 396
—— airship (interior), 432, 448
—— atmospheric, 89
—— centre of, 89
—— closed surface, 89
—— distribution of, 415, 422
—— immersed plane surface, 98
—— liquid, 89
—— of water at various heads, 402
Prices, table of, 635
Prism, volume and surface, 49
Prismatic coefficient, 93
—— —— effect on speed, 171, 176
Prismoid, volume, 50
Product of inertia, 72, 89
Progressive trials, 184
Projectiles, motion and range, 379, 388
—— particulars of various, 380-7
Promenade space, 487
Proof spirit, 263
—— stress and load, 309
Propeller, screw, 190-5
—— —— clearance, 394
—— —— effect of propulsion, 164
—— —— effect on turning, 366
—— —— efficiency, 191, 192
—— shafts, Board of Trade rules, 464
—— —— Lloyd's rules, 506
—— struts. 344

Proportions, effect on speed, 172-6
Propulsive coefficient, 161
——— coefficient (airships), 438
——— ——— values of, 163
Provisions, 505
——— in Navy, 563
——— weight, 108
Pulley, stress in, 328
Pulleys, system of, 354, 362
Pumps, provision of, 475
——— size and duty, 402
Punching, weakness due to, 293
Pyramid, C.G., 61
——— volume and surface, 49
——— ——— ——— of frustrum, 49

QUADRILATERAL, area, 37
——— C.G., 59, 60
Quarters and kilogrammes, 625
——— tons, 629
Quenching steel, 256

RADIAL integration, 46, 65
Radiation of heat, 406
Radius of action, 189
——— curvature, 20
——— gyration, 69 (*v. Moment of inertia*)
——— to draw, 22
Rafts, 500
Rail, height of, 469, 479, 481, 503
Range of stability, 116
Rankine (*re* pillars), 329
Rating of motor-boats and engines, 388
Reaumur temperature scale, 406
Reciprocal diagram, 295
Reciprocals (table), 655
Rectangular bars, weight, 222, 224
——— plates, compressive stress, 330
——— springs, 336
Refrigerators, 465
Register tonnage, 496
Resistance (aeroplanes), 427
——— (airships), 438
——— coefficient, effect of, 201
——— frictional, 166, 410
——— in air, v. *Air pressure*
——— of air in trunks, 397
——— of water in pipes, 404
——— rolling, 152-5
——— (ships), v. *Speed*
Restitution, coefficient of, 88
Resultant acceleration, 82
——— force, 76-9
——— stress, 332
——— velocity, 81
Reverse frames, 507, 512
Reversibility of screws, 356
Revolution, solid of, surface, 56
——— ——— volume, 53
Rigging chain, 529, 538
——— slip and screw, 539, 542
——— standing, 586-9
Rigidity, coefficient of, 310
Ring, cylindrical, volume and surface, 51
——— plane, C.G. of sector, 60
——— strength of, 338
Ripples, 148
Rivet-holes, correction for, 352
——— spacing, 289, 452, 486, 521
Riveted joints, design and strength, 285-94, 452
——— ——— size of butt straps, laps, etc., 289, 290, 452, 521
Rivets, countersink of, 291
——— effect of punching, 294
——— in tension, strength of, 288, 289
——— lengths and preparations of, 291, 292
——— shearing and bearing values of, 286-8
——— tests of, 268-70, 285
Roche Point, distances from, 219
Rod, weight of copper, 234
Rolling of ships, 150-60
——— among waves, 155-7
——— axis of, 151
——— effect of bilge keels, 154, 155
——— observations of, 160
——— period, 150, 151
——— resistance and extinction, 152-5
——— with water chambers, 157-9
Rope, hemp and wire, 572
——— manilla, 283, 573
——— steel wire, 575-82
——— ——— Admiralty, 578, 579
——— ——— Bullivant's, 580-2
——— ——— drums and sheaves, 575
——— ——— Lloyd's, 586-9
——— ——— Newall's, 575-7
——— ——— notes on, 582
——— various, 574
Rota, Colonel (on ship resistance), 172

Round bars, weight, 222, 231, 234
Rudder (airship), 486
——— ships, area, 365
——— head, size of, 369, 371, 522
——— pressure, 367
Rudders, twin, 162, 366
Rule of the road at sea, 469

Σ (SIGMA), 3
Safety, factor of, 309, 311, 329, 450, 451
——— valve, 459
Sailing and sail area, 208, 495, 520, 564
——— rules, 489
——— ship, rig, 586, 593
Screen for bow lights, 487
Screw efficiency, 354, 355
——— propellers, v. *Propeller*
——— rigging, 542, 545, 547
——— steering gear, 81
——— threads, B.S. fine, 536
——— B.S. (pipes), 537
——— B.S. (Whitworth), 533-5
——— form of, 336, 533-6
Screwed bolts, strength, 339
Scuppers, 462
Sea waves, 146, 148, 149
Seacocks, 462
Seasoning timber, 557
Secants, 7 (table), 716
Sectional areas, curve of, 91, 393
Sections, method of, 295
Segment of circle, area, 40 (table), 652
Seller's screw thread, 356
Semicircle or semi-ellipse, C.G., 61
Set, 309
Shackle, anchor, 546
——— bow and straight, 548
——— of cable, 538
Shaft brackets, 344
——— horse-power, 161
——— strength, 334
Shafts, Board of Trade rules, 464
——— Lloyd's rules, 506
Shallow water, effect on speed, 189
——— waves, 147
Shear of rivets, 286-8
——— and resultant stress, 332
——— stress in beams, 332
——— ships, 352
Shear stress working values, 334
Shearing force curve in ships, 347, 352
——— in beams, 300-8
——— when launching, 376
Sheathing bolt, 556
——— copper, 280
Sheaves for S.W. rope, 575, 580
Sheer legs, 298
Sheet metals, weight, 290
Shells, strength, 330
Shift of figure, effect on C.G., 67, 80
Shillings and pence (table), 638
Ship fittings, 538-56
Ships, longitudinal stress in, 315
Shrinkage of castings, 235
Shrouds, Lloyd's rules for, 586-9
——— screw for, 545
Side pressure in air, 397
——— scuttles, 474, 486, 504
Signals, distress, 469, 477, 490
——— fog, 489
Signs and symbols, 1
Simpson's rules, 42-6, 64, 94
Sine, etc., 7 (table), 716
Sirocco fans, 395
Size, effect on ship's resistance, 169
Skin friction, v. *Frictional resistance*
Slackness, 208
Sleeping spaces, air for, 399
Slide rule, 7
Slings for boats, 299
Slip, building, declivity of, 378
— clear hawse, 554
— of propeller, 190, 193, 196
— rigging, 539, 545, 547
Sluice, discharge through, 402
Smooth water limits, 469
Snatch block, 542
Solders, table of, 259
Solid measure, 607, 614
Sounding line, 476
Southampton, distances from, 220
Space necessary for crew, 478, 499
——— passengers, 468, 479-83, 499, 502
Spacing of rivets, 289
Spare gear, 463, 466, 476
Specific gravity, 88
——— heat, 405
Speed and horse-power, 160-90
——— effect of dimensions on, 392
——— form and proportions, 172
——— length, 170
——— size, 169
——— on turning, 366

Speed. frictional resistance, 166
—— loss of, due to foul bottom, etc., 201
—— low, and economical, 190
—— minimum, of aeroplane, 428
—— powering by Admiralty coefficient, 180-4
—— —— approximate data, 185-9
—— —— methodical experiments, 179
—— —— models, 176
—— —— progressive trials, 184
—— propulsive coefficient, 161
—— radius of action, 189, 190
—— residuary resistance, 168
—— shallow-water effect, 189
—— tables, 202
—— trials, 197
—— wake and thrust deduction, 163
Speeds, corresponding, 169, 428
—— of belting, 358
Sphere, air pressure on, 409
—— development of, 81
—— volume and surface, 50
—— —— of segment, 50
—— —— of zone, 51
Spherical shells, strength, 330
Spirit, proof, 263
Springs, helical, stress, etc., 336, 461
Spunyarn for caulking, 598
Square bars, weight, 222, 231
—— measure, 607, 613
—— sections under tension, 336
Squares, square roots (table), 655-99
Stability, 110-43
—— Barnes' method, 118-24
—— change with change of dimensions, 129-31, 391
—— condition for, 110
—— cross curves, 117
—— curves of statical and dynamical, 116
—— direct method, 125
—— dynamical, 115
—— effect of adding weight, 134, 135
—— —— bilging, 138-42
—— experimental determination, 135-8
—— geometrical bodies, 128
—— integrator method, 126
—— large angles of heel, 114-28
—— light draught, 125
—— longitudinal, 131-4
—— metacentre above C.B., 111, 114
Stability, metacentric diagram 112, 113
—— —— height, 112, 114
—— of aeroplanes, 418
—— of ship aground, 142
—— to ensure, in design, 397
Stabilizing plane, 435
Staining wood, 603
Stairways, 503, 604
Stanchions, 469, 479, 503
Stays for boilers 454
Steam pipes, 449, 459
Steel, v. *Mild steel, cast steel*, etc.; for weights, v. *Angle*, etc.
—— notes on, 256
—— tubes, tests, 274
—— wire rope, v. *Rope*
—— wire, weight and strength, 240
—— yachts, 521
Steering (airship), 436
—— chain, 509
—— gear (screw), 81, 356
—— indicator, 364
—— influence of features on, 365
—— path when turning, 364
—— rudder pressure, 367-9
—— rules, 489
—— strength of rudder head, pintles, etc., 369
—— terms used, 364
—— turning trials, 366
Stem, 507, 521
Sternpost, 507, 521
Stiffeners for bulkheads, 322, 324, 483
—— —— webs and plate frames, 333
Stocks for anchors, 533
Stopper, Blake's, 540
Stoves, 463, 466
Stowage of chain cable, 544
—— —— provisions, 563
—— —— substances (various), 562
Strain, longitudinal and shear, 309
—— volumetric, 310
Strength, v. also *Stress* and *Tests*
—— of duralumin, 259
—— —— metals, 260
—— —— miscellaneous substances, 262
—— —— ships under longitudinal bending, 345-52
—— —— steel wire, 240
—— —— structures and fittings (general), 309-12
—— —— —— beams, 312-23, 332

Strength of structure bearings, 336
—— bulkheads, 322, 483
—— couplings, 335
—— cylinders, 330
—— davits, 326
—— derricks, 296
—— flywheels, 328
—— hooks, 338
—— keys and keyways, 339, 340
—— pillars, 328-30
—— plate webs, 338
—— plating under compression, 330
—— plating under lateral pressure, 325
—— rings, 338
—— rudder heads, 369
—— screwed bolts, 339
—— shaft brackets, 344
—— shafts, 333, 344
—— slings for boats, 299
—— springs, 336, 337
—— toothed gearing, 341-4
—— unsymmetrical beams, 326
—— timber, 261
Stress, 309
—— allowable, 352
—— bending, 312
—— in beams under various loadings, 323
—— bulkheads, 322-5
—— cylinders and shells, 330
—— flywheels, 328
—— flat plating under compression, 330
—— lateral pressure, 320
—— unsymmetrical beams, 326
—— longitudinal, in ships, 345-52
—— shear and resultant, 332
—— in beams, 332
—— shafts, allowable, 335
—— springs, 336
—— working, for screwed bolts, 339
Stress working in various materials, 312
Struts, air resistance, 409, 410
—— strength of, 328
Stud-linked cable, 528, 538
Submarine, stability, 128
Suction, bilge, 487
—— pump, 475
Suez Canal dimensions, 578
—— tonnage, 493
Superheaters, 458
Superstructure, strength of, 352
Supplement of angle, 7
Supports to beams, best position, 322
Surface, hydrostatic pressure, 89
—— of geometrical figures, 49-51
—— general solids, 57-9
—— solids of revolution, 56
—— stability, 115
—— wetted, 167
Swivel for cable, 555
Symbols, 1
Synchronous rolling, 156

TACKLE blocks, 568
Tactical diameter, 365
Tangent (of an angle), 7; (table), 716
—— (to curve), 19, 24
Tank, oil, 466
Taylor, D. W., approximate curves of resistance, 186, 187
Tchebycheff's rule, 46, 100, 128
Tee steel, weight and proportions, 226-9, 252
Teeth, shape and strength of, 342
Temperature scales, 406
Tempering steel, 256
Tensile strength of rivets, 288
Tension, airship envelope, 447
Test pieces, 265, 448
Tests, Admiralty, 263
—— brass and copper, 279
—— cable iron, 275
—— canvas, 282
—— cast iron, 276
—— davits and derricks, 265
—— form of test pieces, 265
—— gunmetal, 278
—— indiarubber, 281
—— lead, 280
—— manilla cordage, 283
—— Naval brass, 277
—— phosphor bronze, 279

Tests, steel castings, 272
——— forgings, 270-2
——— plates, bars, and rivets, 265-70
——— tubes, 274
——— wood, 281
——— wrought iron forgings, 274
——— zinc, 281
——— Board of Trade, 448
——— hydraulic, for boilers, 447
——— plates and rivets, 449
——— tubes, forgings and castings, 450
——— anchors, 527
——— cable, 528
——— chain, 529
———(Lloyd's), 284, 285
Thames, distances down, 212
Thermal properties of materials, 405
Thickness of propeller blades, 194
Thimbles, 538
Thomson's rule, 46
Thread, screw, 356, 533-7
Three-ten rule, 68
Thrust deduction, 163-5
——— horse-power, 164, 191
Tides, 566, 604
Timber loads, 636
——— measure and conversion, 559
——— preserving, 558
——— seasoning, 557
——— to cut beam from, 20
Time and knot table, 202
— to empty compartment (air), 400
——— (water), 403
Tin, notes on, 257
Tonnage, 490
——— yacht, 495, 520
Tons and kilogrammes (table), 625, 626
——— lb., qr., cwt. (table), 628, 629
——— per inch, 92, 93
——— curve, 92
Toothed gearing, 341
Topmasts, 585
Torque on rudder head, 370
Torsion, 333, 334
Towing trials, 195
Tow line, provision of, 531
Towne's hook, 338
Tracing-paper, 604
Transverse number (Lloyd's), 507
Trapezoid, area, 36, 145
Trapezoid, C.G., 59
——— moment of inertia, 75
Trapezoidal rule, 43
Tray for motor, 468
Tresidder's formula, 378
Triangle, area, 11, 36
——— C.G., 59
——— moment of inertia, 75
——— properties of, 10
——— solution of, 11, 12
Trigonometrical ratios (certain angles), 12
——— (general), 716
Trigonometry, 7-13
——— general formulæ, 9
Trim, 131-3
— due to gyroscopic action, 87
— effect on speed, 170
Trochoid, 18, 88, 145
——— to draw, 34, 345
Trochoidal wave theory, 144
Troy weight, 606
Trunking, air, 395, 401
Tube plates, 457
Tubes steel, tests for strength, 274, 450, 454
Tugs, propulsive data, 195
Turbine machinery, particulars of, 389, 390
——— shafts, 465
Turning trials, 366
Twist of shafts, 333
Twisting moment, equivalent, 332
——— in shafts, 333, 334
Two-thirds powers (table), 184
Tyne, distances down, 217

ULTIMATE strength, 309
Uneasy rolling, 151
Uniform force, 85
Universal joint, 361, 549
Unsymmetrical beams, 326, 327
Unwin, factor of safety, 311
Useful numbers, 637

VALVE, safety, 459
Varnish, 595, 599
Velocity, angular, 82
——— composition of, 81
——— diagram, 81, 82
——— of air, 399
——— projectiles, 379-83
Ventilating fans, 395
Ventilation, 396-401
——— of crew space, 477
——— motor compartment, 467

Ventilators, 401
Vibration, frequency of, 86, 337
Vickers' guns, particulars of, 383
Volume of fourway piping, 56
——— geometrical solids, 49-53
——— solids in general, 53-5
——— of revolution, 53
——— wedges, 55
Volumetric strain and modulus, 310

WAGES table, 638
Wake, 163-5, 191
Wall-sided ship, stability, 128
Warships, anchors and cables, 535
Waste in converting timber, 561
Water, admission to ship, 138-42
——— and air, comparison of results in, 431
——— chambers (anti-rolling), 157-9
——— closets, 462, 478, 480, 504
——— discharge from orifice, 403
——— flow through pipes, 403
——— free surface effect, 139
——— fresh, allowance, 108, 505
——— pressure at various heads, 402
——— pumps, pipes, etc., 402
——— weight of fresh and salt, 225
Water-line coefficient, 93
——— effect on stability, 391
Watertight subdivision, 473, 478, 486
Watt, 85
Watts, Sir Philip (*re* water-chambers), 157
Wave assumed in strength calculations, 345
——— slope, effective, 155
Waves, 143, 144
——— accompanying ship, 168 ff.
——— effect on rolling, 155-9
——— energy of, 145
——— momentum of, 146
——— period, apparent and real, 149
——— periods and lengths (table), 146
——— pressure within, 145
——— ripples, 148
——— sea, dimensions of, 148, 149
——— shallow water, 147
——— subsurfaces of, 144
——— trochoidal, standard, 345
Ways, launching, 376-8
Wedge, O.G., 67
Wedge, effect of, 333
——— volume, 55
Weight curve for ships, 346-8
——— effect of addition to ship, 134, 392
——— of air, 396
——— airship, 437
——— armament, 108, 380-7
——— armour, 108
——— bars, round and elliptical, 222
——— ——— square and rectangular, 222
——— boats, 565
——— cable, 528
——— chain, 529
——— cast-iron balls, 234
——— ——— pipes, 233
——— copper rods and pipes, 234, 235
——— earths, etc., 636
——— equipment, 108
——— fresh water (constants), 223
——— hoop iron, 236
——— hull, 103-7
——— lead pipe, 234
——— machinery and fuel, 108, 390
——— malleable flat steel, 224, 225
——— ——— iron pipes, 232
——— metals, 260
——— miscellaneous substances, 262
——— nuts and boltheads, 236
——— pipes and angles, rules for, 223
——— plating and planking, 222
——— salt water (constants), 223
——— sheet metals, 230
——— ship, 102-9
——— ship when launched, 374
——— steel angle and T, 226-9
——— ——— round and square, 231
——— ——— wire, 240
——— ——— ——— rope, 575-81
——— timber, 261
——— wire of various metals, 236
Weights and properties of B.S. bulb angles, 250
——— ——— bulb tees, 253
——— ——— channels, 244
——— ——— equal angles, 246
——— ——— tees, 252

Weights and properties, unequal angles, 248
——— Zeds, 254
——— comparison, English and metric, 615-38
——— English, 606
——— foreign and English, 633
——— metric, 614
——— miscellaneous, 609-12
Weston pulley blocks, 567
Wetted surface, 167
White, Sir William H., re waves, 149
White metal, 258
Whitworth thread, 583
Wicklow, distances from, 214
Winch, Bullivant's crab, 583
Wind, force of, and Beaufort scale, 210
——— real and apparent motion of, 209
Wine measure, 607
Wire, air resistance of, 409
——— gauge, legal standard, 239
——— weight and strength, 236, 240
Wood cleat, 542
——— fuel per H.P. per hour, 390
——— staining, 603
——— weight and strength, 261
Wood yachts, scantlings, etc., 521
Wool measure, 609
Woolley's measure, 54
Work, 84
——— done in extinction, 153
——— by men and animals, 360
Working load and strength, 309
——— shear stress, 334
——— stress (direct), 312
Wrench, 79
Wrought iron, 255
——— chest, 554

YACHT tonnage, 495, 520
Yachts, international racing, 520-6
Yards, 584, 590
——— feet and inches, 630
Young's modulus, 260, 310, 311

ZAHM'S formula for air friction, 410
Z-bars, B.S., weights and properties, 254
Zigzag riveting, 298
Zinc, 257, 281
——— for galvanizing, 605
——— plates, weight, 230

Stephen Austin and Sons, Limited, Printers, Hertford.